Engineering Library
MAY 15 1922

VOL. 9 NO. 3 MAY, 1922

PROCEEDINGS 42ND YEAR

JOURNAL

OF THE

AMERICAN WATER WORKS ASSOCIATION

PUBLISHED IN JANUARY, MARCH, MAY, JULY, SEPTEMBER AND NOVEMBER

BY THE

AMERICAN WATER WORKS ASSOCIATION

AT MOUNT ROYAL AND GUILFORD AVENUES, BALTIMORE, MD.

SECRETARY'S OFFICE, 153 WEST 71ST ST., NEW YORK
EDITOR'S OFFICE, 16 WEST SARATOGA STREET, BALTIMORE, MARYLAND

Subscription price, $7.00 per annum

Entered as second class matter April 10, 1914, at the Post Office at Baltimore, Md., under the act of August 24, 1912. Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917; authorized August 6, 1918

COPYRIGHT 1922, BY THE AMERICAN WATER WORKS ASSOCIATION

Made in United States of America

R. D. WOOD & CO.

PHILADELPHIA, PA.

MANUFACTURERS

OF

MATHEWS FIRE HYDRANTS

Standard and High Pressure

CAST IRON PIPE

Bell and Spigot—Plain Ends—Flanged—High Pressure
Fittings of every description

VALVES

Gate—Check—Foot—Indicator

PUMPS

Centrifugal Pumps—Hydraulic Pumps—Pumping Machinery

GAS WORKS MATERIAL

JOURNAL

OF THE

AMERICAN WATER WORKS ASSOCIATION

The Association is not responsible, as a body, for the facts and opinions advanced in any of the papers or discussions published in its proceedings
Discussion of all papers is invited

VOL. 9 MAY, 1922 No. 3

APPLIED HYDROGEN-ION CONCENTRATION—A STUDY OF ITS MERITS IN PRACTICAL FILTER PLANT OPERATION

BY A. WAGNER[1] AND LINN H. ENSLOW[1]

During the past year there has appeared in the literature considerable new thought concerning water purification and sewage treatment.

The writings of Wolman and Hannan[2] and of Massink and Heymann[3] contained such information as to warrant an investigation into the merits of pH application to the control of coagulation at the various filter plants in Virginia, as a practical means of solving coagulation difficulties or of increasing plant efficiency in other ways.

The technique of pH observations is of such simplicity and the apparatus required so easily manipulated as to make the adoption of routine pH observations appear desirable. The only remaining question in the authors' minds was: "Are we justified in advising the adoption of pH observations as routine at any plant, until we have made a study of its merits where applied to waters of the char-

[1] State Department of Health of Virginia, Richmond, Va.

[2] "Residual aluminum compounds in filter effluents," Chemical and Metallurgical Engineering, vol. 24, no. 17, April 27, 1921.

"Further observations on pH in natural waters," Chemical and Metallurgical Engineering, vol. 25, no. 11, September 14, 1921.

[3] "Significance of pH in drinking water and particularly for the business of water supply," JOURNAL, vol. 8, no. 3, May, 1921.

acter handled in Virginia? If the tests are applicable what may we offer the prospective users of the "new" test as a good and logical reason why they should employ them and, more important, when, where and how often should they be made, if used as a routine control test?"

In order to answer these questions to our satisfaction, an investigation was begun with the idea of testing Tillman's formula, slightly modified by the authors, as a means of calculating the pH, CO_2 or alkalinity content of waters, when any two of the three members have been determined from observation or titration. The second and really important matter to investigate was that of operation economics. *Could we reduce the alum bill and at the same time improve the qualtiy of filtered water?* After improving the quality of the filtered water could we improve the chemical and physical quality of the water as delivered to the consumer, by removing or absorbing a portion of the free carbon-dioxide from the filtered water? In other words, was it practical to remove a portion if not all of the free CO_2 from the water in the clear well, thereby reducing its corrosive quality. As a result of such treatment would there be a reduction of consumers' complaints in direct proportion to the reduction of "aggressivity" of the water in the mains and of "red-water" at the taps? In the belief that all of the questions could be answered in the affirmative, the authors undertook to prove it through the aid of the pH measurements, as an added method of plant-control.

It might be well at this point to explain why the recent ideas of coagulation-control through pH regulation of the coagulated-water appealed so much to the writers. Having been in charge of water purification at various plants in the past, practical experience had demonstrated that the following conclusions are valid.

1. That waters aerated even immediately after alum had been added were slower to coagulate properly than when aeration was not resorted to—organic waters of low alkalinity excepted.

2. That certain waters required the addition of artificial alkalinity during coagulation. In such cases better coagulation and more effective color-removal could be had by withholding the alkali addition until the water had reached a point in the settling-basins as near to the filters as was practical for the production of a satisfactory applied water.

3. That in any event a very careful control of the alkali addition was required to avoid the so-called "setting of organic color" or

the production of a "milky" effluent. To avoid these undesirable conditions an alkali dose was required of such proportion that the alkalinity of the applied water should vary but little. This "alkalinity zone." within the limits of which a satisfactory applied water resulted, was narrow. It was necessary to maintain an alkalinity of applied water not higher than 3 to 5 parts below that of the raw-water and often considerably less. If the alkalinity was not kept up in the "zone" having a maximum variation of about 6 p.p.m. alkalinity, troubles would ensue. Too low alkalinity with high free CO_2 meant a floc of poor settling quality and also the air-binding of filters by CO_2. Too high an alkalinity meant a "setting of the color" and "milky" filtrate containing aluminum compounds. All three qualities we now believe to have been due to solution of or possibly the "peptization" of the alumina "floc," with the resulting release of adsorbed coloring matter and the passage of both through the sand bed. Too great an alkalinity will furthermore in some cases tend to peptize or dissolve the "mat" already on the sand-bed and also the film which always surrounds the sand grains. An old custom now discarded, was to clean the filter sand-bed of mechanical filters at regular intervals by allowing a dilute soda-ash solution to remain in contact with the dirty sand for some hours and later sterilize the bed with live steam. Such practice was abandoned because filters produced poorer bacterial results after such treatment than prior to it. The probable explanation lies in the fact that the "films" were peptized or dissolved and thereby removed from the sand. After such treatment there was probably insufficient "coagulum" remaining in the filter tub to form an effective "mat" after washing with filtered water. The bacteria therefore literally "slipped" over the sand grain surfaces and through the filter-bed.

4. Operation of certain plants treating river waters which would vary in alkalinity, color and turbidity with seasonal changes always ran into coagulation difficulties, necessitating a relatively high alum dose whenever the alkalinity ascended to 80 p.p.m. with attending low CO_2 and turbidity content. It was apparent that most of the difficulty could not be atrributed to the low turbidity, since this was often very low when the alkalinity was 40 to 60 p.p.m. and with a CO_2 content of 2 to 4 p.p.m. It appeared that some means was necessary to reduce the alkalinity. This was being accomplished through the certain but expensive method of adding more alum to the water. No real thought had been given to the rôle played by

the CO_2 content in such instances. Now we believe that the larger alum dose was acting as "pH reducer" through an alkalinity reduction and CO_2 increase, both or either of which accomplishments would serve the purpose of producing the so-called "optimum point" of coagulation or preparing the "pH zone" in which satisfactory coagulation results.

It is our intent to make further investigations of such waters during the next fall at which time the alkalinity rises. An attempt will be made to produce the proper "pH zone" or obtain the "optimum point" for proper coagulation through addition of a small quantity of sulphuric acid to the alum solution or perhaps by gassing the raw-water in the mixing chamber with CO_2, making use of liquid CO_2 in cylinders and applying it through large diffusers. In the limestone section of Virginia are streams of high alkalinity (200 p.p.m.) and low CO_2 content. Some are being considered as sources for future filter plants. Investigation of coagulation of such waters will be made by the writers in the immediate future.

5. During the past two years, duty has carried us to many different filter plants where we have met with a variety of waters of varying qualities. Experience has shown us that where artificial alkalinity addition is necessary the following "laws of coagulation" *must* be "enforced" in this state:

a. In no case allow the alkalinity of the treated water to exceed that of the raw-water. Cases of exceptionally high CO_2 content of un-aerated raw-water are excepted.

b. If free CO_2 in the filter effluent is of sufficient concentration as to cause serious red-water troubles, CO_2 must not be absorbed by alkali addition prior to filtration even though such is added to the filter influent chamber.

c. In cases where the CO_2 content of a filtered water must be reduced, this shall be accomplished by aeration of the filtered-water or absorption of the CO_2 by alkali prior to pumping into the mains.

From the above it is readily seen that we were headed in the direction of obtaining efficient filtration, although the scientific reasons were not known to us. Upon the appearance of the first article by Wolman and Hannan, pointing to the rôle played by pH in coagulation and settling of waters, there was one thing definitely apparent. The thought that it must necessarily be pH which was to direct our future procedure of scientific coagulation control found a fertile field and, therefore, the authors undertook the preliminary investi-

gation of the matter which is the subject of this article. The incentive furnished by Wolman and Hannan has led us to certain valuable knowledge regarding pH determination, its theory and its practical value. What is of more importance however, is that economy of alum use and the abatement of the red water nuisance have resulted from the study. Credit for the elimination of red water, we acknowledge to Massink and Heymann for the original and to Wolman and Hannan for their industry in causing its publication in available form. We hope that our endeavors may result in a slight addition to the data already published and that this article may be of value to others who are giving thought to the question of pH and its merits in the practical field of filtration.

METHODS PURSUED IN THE INVESTIGATION

Ampules of pH color standards and indicator solutions were obtained from the La Motte Chemical Company of Baltimore. Each author having a complete set and a field kit fitted for making CO_2 and alkalinity determinations, various plants were visited and readings of alkalinity, CO_2 and pH were made. Several plants were re-visited in some cases as many as four times for the purpose of obtaining varied conditions at the plant.

Having obtained the required data on existing raw, coagulated and filtered waters, experiments were made along the lines of varying the alum or alkali dose, in each instance taking readings and recording the quality of "floc" and its behavior. Changes in the point of application of alkali also were made. At some plants it was discontinued in the raw water and applied first to the filter influent and later discontinued at this point and application made instead to the filter effluent. At other points it was necessary to apply a portion of the alkali to the raw water. The alkali dose was increased by degrees, readings made and observations noted. The dose was then increased to a point where the "floc" was destroyed. From this point it was again lowered until the most satisfactory "floc" in the series was obtained. In some cases "jar" tests were made at the plant. This was done only where it was impossible without considerable trouble to the personnel operating the plant and expense to the municipality, to have equipment for alkali feed put in or the existing location changed.

The experiments were carried out using raw water and varying combinations of alum, soda-ash, limewater, finely ground limestone,

finely ground sand and sulphuric acid. These experiments are interesting from the standpoint of the investigation, but since this paper is intended primarily to cover actual operating conditions, as existed or were created, at the various plants and as a means of testing the merits of pH control and Tillman's formula, we will not attempt to describe in detail the jar experiments. We shall outline the results from these experiments, touching on the principal points and only include in tables presented the measurements and data as obtained from actual plant operation.

In the jar experiments ½ gallon of raw water was taken. Prepared solutions of known strength carried in the kit were used to create the desired combination of chemical doses.

The results obtained indicate:

1. Where alkali is added in coagulation, the "floc" is materially hurt as soon as pH 7 is exceeded and at pH 7.3 little if any coagulation results.

2. Most satisfactory coagulation was obtained in the pH zone 6.5 to 7 for the non-organic waters. For organic waters the pH zone extended as low as 5.7 pH but never above 6.5 pH.

3. Such waters as were experimented with required no acid addition to improve coagulation. The addition of acid produced inferior coagulation even though the pH was 6.65 for the coagulated water.

Note: The pH of raw water was 7.5, but 2.5 grains per gallon of alum produced a good "floc" with resulting pH of 6.8. The alkalinity of the raw water was only 41 and CO_2 content, 2 parts. Waters of higher alkalinities and low CO_2 *may* be benefited through acid addition.

4. Addition of finely ground limestone during coagulation, followed by a two-minute vigorous mixing, always produced an improved "floc" and more effective settling.

Note: Limestone apparently had very little effect chemically. CO_2 was only one part less and alkalinity only two parts more in the coagulated water to which limestone had been added just prior to alum addition than was the case with coagulated water receiving the same alum dose but no limestone. There was an increase in pH from 6.1 to 6.3 or only 0.2 in the limestone treated water.

5. Finely pulverized cinders or sand added during coagulation, followed by a two-minute vigorous mixing, produced an improved "floc" and more effective settling.

Note: The "floc" produced by grit addition was equally as good if not superior to that produced by limestone and also superior to

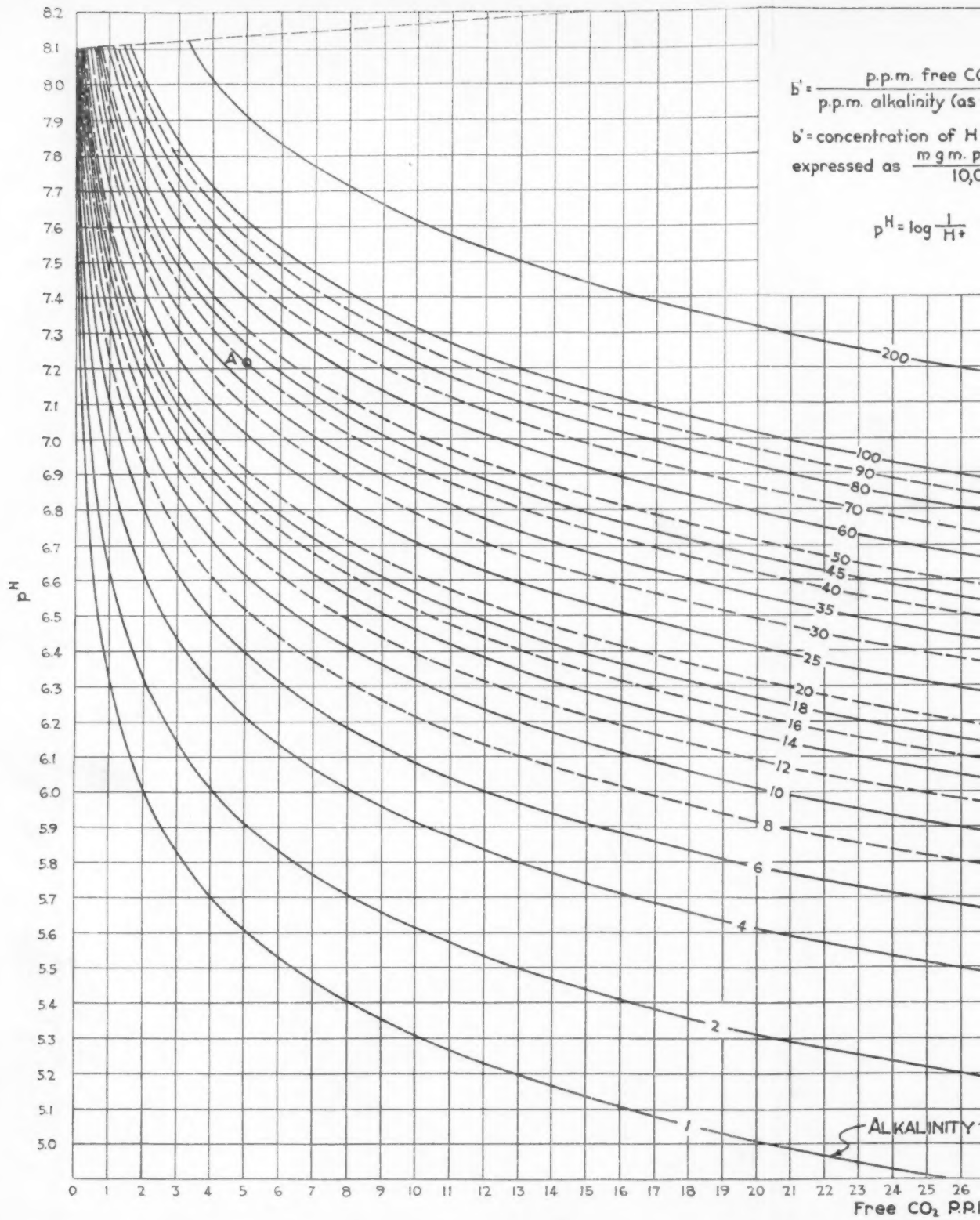

b' = p.p.m. free C
p.p.m. alkalinity (as
b' = concentration of H
expressed as m g m. p
10,0
pH = log 1/H+
pH
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
7.0
6.9
6.8
6.7
6.6
6.5
6.4
6.3
6.2
6.1
6.0
5.9
5.8
5.7
5.6
5.5
5.4
5.3
5.2
5.1
5.0
A
200
100
90
80
70
60
50
45
40
35
30
25
20
18
16
14
12
10
8
6
4
2
1
ALKALINITY
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
Free CO2 P.P.

FIG. 1

n. free CO_2

alinity (as $CaCO_3$) × 0.61

ion of H^+

m g m. per liter

10,000

$= \log \frac{1}{H^+}$

ALKALINITY CURVES

Showing p^H value for CO_2 content 0 to 50 p.p.m.

Calculated from "Tillman's" formula by A. Wagner

from which calculated alkalinity, CO_2, and p^H concentration may be found, when any two of the three factors are known

Example

Alkalinity-40 p.p.m. CO_2-5 p.p.m. to find p^H

5 CO_2 line & 40 alkalinity curve intersect at point "A" taking horizontal line to left p^H = 7.21

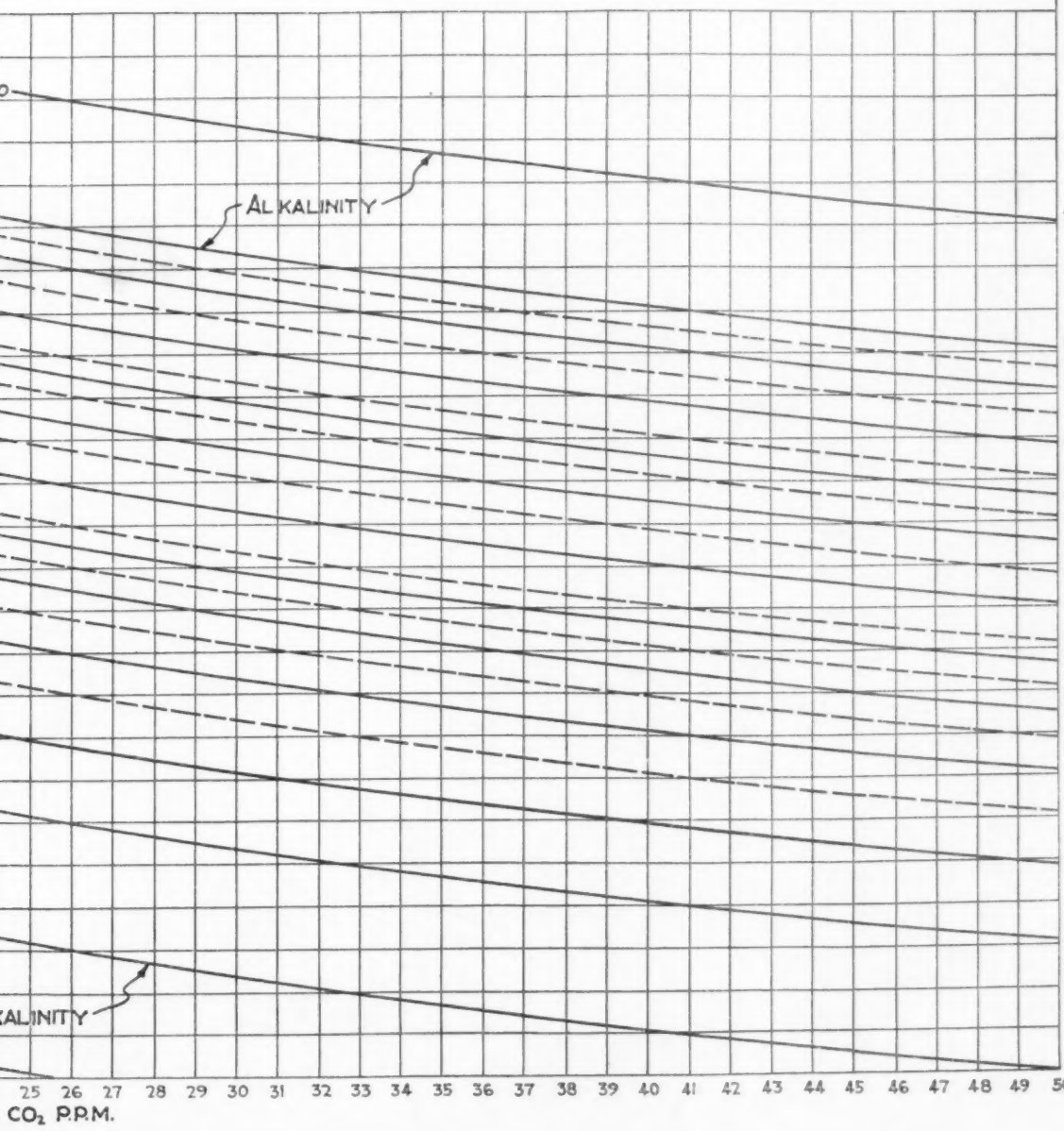


FIG. 1

any alum dose alone or combination of alkali and alum, except in instances where sufficient alkalinity did not exist in the raw water to furnish the required hydroxyl-ions to combine with the alum added and completely to decompose it.

THE TESTING OF TILLMAN'S FORMULA AND ANALYSIS OF DATA

The first step was the preparation of figure 1. This chart was prepared through use of Tillman's formula for calculating the theoretical pH of waters containing only bi-carbonate alkalinity and carbon-dioxide from zero upwards.

$$*(1) \quad h' = \frac{(\text{p.p.m. free } CO_2) \times 3}{(\text{p.p.m. bi-carbonate alkalinity expressed as } CaCO_3) \times 0.61}$$

$$(2) \quad h' = \frac{H+}{10^{-7}} \qquad (3)\ H+ = h' \times 10^{-7} \qquad (4)\ pH = \log \frac{1}{H+}$$

$$*h' = \text{concentration of } H^+ \text{ expressed as } \frac{(\text{mgm. per liter})}{10{,}000.}$$

To prepare these curves, each alkalinity shown was taken with each CO_2 content shown. The pH was calculated, the points were plotted and then the curves were drawn through them. (Fig. 1.)

Having completed the chart it was then tested at several points in the following manner:

The alkalinity, CO_2 content and pH were carefully determined on a filtered-water. Using alkalinity and CO_2, the theoretical pH, as found from the curve, checked with the pH observed within the limit of error of observations. Using this same water and artificially varying its CO_2 content and alkalinity, further observations and checking were carried out. The final alkalinity was 162 p.p.m. with a CO_2 content of zero. Tillman had claimed accuracy of the formula only where the ratio of free CO_2 to alkalinity is not less than 1 p.p.m. CO_2 to each 65 p.p.m. alkalinity, and therefore as expected the pH as found from the curve was materially higher than that observed, as soon as this ratio no longer held. For example, an alkalinity of 55 (all bicarbonate) and CO_2 of 0 when using the chart indicates a theoretical pH of about 9, whereas the observed pH was 8.1.[4] The alkalinity of 162 (all bicarbonate) and CO_2 of

[4] From laboratory observations it would appear that a trace of normal carbonate alkalinity irrespective of bi-carbonate alkalinity produces pH 8.1 according to the pH standards purchased, which were prepared from phenol red up to pH 8.4.

zero from the chart indicates a theoretical pH of about 9.53, whereas the observed pH was 8.1.[4] We have discontinued on this account the alkalinity curves at points on their upward swing above which, if used, they would be plainly in error. We cannot claim that the curves are perfect even yet, but for all practical purposes they are extremely serviceable, as will be shown later. For the purpose of pointing out under what conditions the greatest inaccuracy may be expected, when the chart is used to arrive at an unknown—the two other quantities necessary having been observed—the following is stated:

1. *Concerning bi-carbonate waters of any alkalinity and varying CO_2 content.* An error of 1 p.p.m. in CO_2 titration will cause an error of calculated pH of from only 0.05 at 10 p.p.m. CO_2 to as much as 0.3 at 1 p.p.m. CO_2. Within the CO_2 range 1 to 0 a fractional p.p.m. CO_2 error will result in even greater error of calculated pH.

2. *Concerning bi-carbonate waters of any CO_2 content and varying degree of alkalinity.* An error of 1 p.p.m. in alkalinity titration will cause an error of calculated pH of as much as 0.3 in waters of 1 p.p.m. alkalinity, whereas an error in pH of only 0.02 would result from an error of as much as 5 p.p.m. titrated alkalinity in waters of 100 p.p.m. alkalinity.

As a result of the above, the following conclusions relating to the use of the chart, where accuracy is desired, are set forth.

1. *Concerning waters of bicarbonate alkalinity of 5 or less. a.* When CO_2 is less than 6 p.p.m., observe the pH, titrate the alkalinity and locate the calculated CO_2 content.

b. When CO_2 is greater than 6 p.p.m., observe the pH, titrate the CO_2 carefully and locate the calculated alkalinity, or titrate the alkalinity and CO_2 and locate the calculated pH.

2. *Concerning waters of bi-carbonate alkalinity greater than 5. a.* When CO_2 is less than 10 p.p.m., titrate the alkalinity, observe the pH and locate the calculated CO_2 content.

b. When CO_2 is greater than 10 p.p.m., titrate the alkalinity, and observe the pH, or locate the calculated pH after titrating the CO_2. Both methods are of like accuracy.

3. *Concerning bi-carbonate waters of any alkalinity and CO_2 less than 1.* Observe pH, titrate alkalinity and locate the calculated CO_2.

Note: Whenever the proportion of CO_2 is less than 1 p.p.m. for each 65 p.p.m. of alkalinity present the accuracy of calculated pH is materially affected—always being greater than that observed.

ANALYSIS OF FILTER PLANT DATA

Having collected the desired data at fourteen plants and at several under different conditions of the water being treated, the next step was that of analyzing these data. Table 1 was prepared for this purpose. The observed pH, CO_2 and alkalinity of each test are recorded in columns (O) indicating observed values. In the column (C)—one to the right under each heading—were placed the values found through the use of figure 1 or, in other words, theoretical values, assuming the two other factors to have been correctly determined in the actual observations and titrations.

Seeing that a good portion of the observed values failed to check with the calculated it was decided to divide the table into sections A and B. In section B were placed all tests wherein calculated and observed pH values differ by more than pH 0.10. This particular degree of variation was chosen because we believe such a difference to be of no consequence in the practical application of the chart for ascertaining the pH of a particular water in filter-plant control, unless it should happen to hit about pH 7 or 7.1 at which point 0.1 pH is of moment in coagulation of non-organic waters.

Upon examining table 1 it will be seen that 62 of the 95 tests fall in section A, and 33 fall in section B, which is equivalent to saying that 65 per cent of the samples showed calculated values comparing favorably with observed values, whereas 35 per cent failed to agree by less than 0.10 pH.

For convenience we show in table 2 the various plants and the proportion of tests made at each which fall within the satisfactory range. Above the line are plants which have more than 60 per cent of tests falling in section A, and below the line those which have the majority of tests in section B. If we are allowed to eliminate the two Bedford tests and the one Hopewell test, which we admit are not of much value because of the small number and the lack of tests on treated water in one and raw water in the other, we will then have only two plants of the fourteen in which there is an indication of the material failure of application of calculated values for pH, etc., as compared with the observed values. At present we have no adequate explanation as to why Norfolk and Petersburg fail to fall in the satisfactory class. The Richmond and Scottsville waters also did not check as perfectly as was desired. Further study must be made of these waters.

TABLE 1A

Table showing comparison of observed values and values obtained through use of theoretical curves plotted from formula

PLANT	RAW						COAGULATED						FILTERED						REMARKS
	Alkali		CO_2		pH		Alkali		CO_2		pH		Alkali		CO_2		pH		
	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	
Alexandria...	11.0	12.0	4.0	3.8	6.80	6.75	10.0	11.8	6.0	5.1	6.6	6.53	10.0	9.8	7.0	7.2	6.45	6.46	
Alexandria...	9.0	7.8	3.5	4.1	6.65	6.72	11.0	12.3	4.0	3.5	6.8	6.74	10.0	10.3	3.0	2.8	6.85	6.83	
Alexandria...													11.0	10.0	5.0	5.5	6.6	6.65	Soda ash added to filter effluent
Clinchfield...	80.0	77.0	44.0	46.0	6.55	6.57	70.0	70.0	36.0	36.0	6.60	6.60	60.0	57.0	46.0	48.3	6.40	6.42	Mixture of creek and deep well water
Danville.....	22.0	25.5	1.5	1.3	7.55	7.48	10.0	9.8	7.0	7.2	6.45	6.46	12.0	11.0	5.0	5.5	6.65	6.69	No soda ash used. Good floc
Danville.....	16.0	17.3	2.5	2.3	7.15	7.11	13.0	12.2	5.0	6.2	6.7	6.72							Soda ash used = ½ alum. Good floc
Danville.....	16.0	17.3	2.5	2.3	7.15	7.11	32.0	41.0	1.5	1.2	7.75	7.63	No coagulation—too much soda ash.						Floc probably peptized
Danville.....	16.0	17.5	2.5	2.3	7.15	7.12	5.0	5.0	10.0	10.0	6.0	6.0							Dead floc—opalescent effluent. No soda
Danville.....							17.0	21.5	3 5	2.75	7.10	7.00							
Franklin.....	15.0	15.0	3.0	3.0	7.0	7.0	3.0	3.6	7.0	6.0	6.0	5.92	3.0	3.6	7.0	6.0	6.0	5.92	Organic water-color = 90 Alum only used with improved coagulation. Soda ash to be added to filter effluent
Lynchburg...	9.0	9.3	3.0	2.9	6.8	6.79	8.5	8.7	4.0	3.8	6.65	6.64	8.5	8.7	4.0	3.8	6.65	6.64	Soda ash used in coagulation. Good floc
Monroe.....	10.5	12.0	2.5	2.2	7.0	6.93	8.0	6.8	3.5	4.2	6.60	6.67	See section B						
Orange.....	9.0	10.3	1.5	1.3	7.15	7.09	7.0	6.3	10.0	11.2	6.10	6.15	8.0	8.5	3.5	3.3	6.7	6.67	Soda ash used = ½ of alum

Petersburg...	31.0	29.5	3.0	3.2	7.30	7.32	22.0	22.0	9.0	9.0	6.70	6.70	23.0	19.8	8.0	9.3	6.70	6.77	No lime used
Petersburg	30.0	29.5	3.0	3.1	7.30	7.31	21.0	17.6	7.0	8.3	6.70	6.78	21.0	19.5	7.0	7.5	6.75	6.79	No lime used
Petersburg...													18.0	16.5	6.0	6.5	6.75	6.78	
Petersburg...													28.0	28.2	4.0	4.2	7.15	7.16	0.12 g.p.g. lime added to filter effluent
Petersburg...	40.0	34.0	3.0	3.6	7.35	7.43						See section B							
Petersburg...			See section B				33.0	30.0	6.0	6.7	7.0	7.05			See section B				
Petersburg...			See section B				33.0	31.5	5.0	5.4	7.1	7.12			See section B				
Petersburg...			See section B				16.0	13.5	7.0	8.3	6.60	6.67							
Richmond...			See section B				23.0	26.5	8.5	7.5	6.80	6.78							
Richmond...			See section B				26.0	22.0	5.5	6.6	6.90	6.98			No filters				Alum only. Purification by setting.
Richmond...			See section B				25.0	24.5	5.5	5.7	6.95	6.97							
Richmond...			See section B				18.0	19.5	8.0	7.3	6.70	6.66							
Richmond...			See section B				6.0	6.2	10.0	9.7	6.10	6.08							
Scottsville....			See section B				35.0	27.5	5.0	6.3	7.05	7.15	38.0	39.5	4.0	3.8	7.30	7.28	
Scottsville....			See section B						See section B				38.0	37.5	3.0	3.1	7.4	7.41	Soda ash added to filter effluent
Suffolk.....	10.0	12.2	5.0	4.8	6.7	6.61	4.0	4.3	8.0	7.25	6.05	6.01	4.0	4.3	8.0	7.25	6.05	6.01	Lime and alum in coagulation. Color R. W. 120
Suffolk.....	10.0	12.2	5.0	4.8	6.7	6.61	4.0	3.95	8.0	8.15	6.00	6.01	4.0	3.95	8.0	8.15	6.0	6.01	Alum dose reduced. No lime
Suffolk.....	10.0	12.2	5.0	4.8	6.7	6.61	3.5	3.5	7.0	7.0	6.00	6.00	4.0	4.2	7.0	6.4	6.10	6.06	Alum further reduced. Good floc
Suffolk.....	10.0	12.2	5.0	4.8	6.7	6.61	2.0	2.0	8.0	8.0	5.7	5.7	2.0	2.2	7.0	6.4	5.8	5.77	In determination of CO_2 some error due to organic acids

TABLE 1B

Table showing comparison of observed values and values obtained through use of theoretical curves plotted from formula

PLANT	RAW						COAGULATED						FILTERED						REMARKS
	Alkali		CO_2		pH		Alkali		CO_2		pH		Alkali		CO_2		pH		
	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	
Alexandria...	11.0	15.5	5.0	3.5	6.8	6.65	3.5	5.6	9.0	5.7	6.1	5.88	3.5	5.6	9.0	5.7	6.1	5.88	Explanation not known
Bedford.....													5.0	7.6	3.5	2.3	6.65	6.47	Explanation not known
Bedford.....													5.0	9.5	3.0	1.6	6.8	6.53	Explanation not known
Hopewell.....	47.0	30.0	3.0	4.8	7.30	7.50													Explanation not known
Monroe.....							See section A						9.0	5.0	2.5	4.5	6.6	6.87	Explanation not known
Norfolk.. ...	22.0	43.0	7.0	3.5	7.10	6.80	6.0	13.2	19.0	8.60	6.15	5.81	7.5	12.7	18.5	10.5	6.15	5.93	Supply to be further investigated
Norfolk.....	25.0	17.5	4.0	5.7	6.95	7.10	21.0	18.0	9.0	10.6	6.60	6.68	20.0	15.5	8.0	10.3	6.60	6.71	
Petersburg...	41.0	26.5	3.0	4.7	7.25	7.44	35.0	52.0	6.0	4.5	7.25	7.07	35.0	58.5	6.0	4.5	7.30	7.07	Further study is required to find why so great a proportion of Petersburg fall in section B
Petersburg...			See section A				32.0	17.5	7.0	12.7	6.7	7.03	32.0	14.5	6.0	12.7	6.70	7.03	
Petersburg...	41.0	30.0	3.0	4.2	7.30	7.44			See section A				34.0	24.0	6.0	8.6	6.9	7.06	
Petersburg...	36.0	24.0	3.0	4.6	7.20	7.38			See section A				29.0	22.0	7.0	9.2	6.8	6.93	
Petersburg...	32.0	24.0	3.0	4.1	7.20	7.32	23.0	17.5	7.0	9.3	6.7	6.83	23.0	17.5	7.0	9.3	6.7	6.83	
Petersburg...	26.0	16.0	1.5	2.3	7.35	7.55			See section A				18.0	13.5	7.0	9.1	6.6	6.72	
Petersburg...													23.0	14.5	6.0	9.3	6.7	6.9	
Richmond...	41.0	27.0	1.75	2.60	7.5	7.66			See section A						No filters				0.75 CO_2 error in raw = 14 p.p.m. alkalinity
Richmond...	23.0	44.0	4.0	2.2	7.35	7.07			See section A						No filters				Turbid raw water possibly gave false pH
Richmond...							16.0	12.5	8.0	10.3	6.50	6.62			No filters				Quality of water similar to Petersburg. Requires further study.
Scottsville....	33.5	17.0	1.5	3.15	7.35	7.67							See section A						Calculated results inaccurate because of low CO_2

TABLE 2

Showing various plants and per cent of tests satisfactory (section A) compared with per cent tests unsatisfactory (section B)

	NUMBER OF TESTS IN SECTION		PER CENT OF TESTS IN SECTION	
	A	B	A	B
Alexandria	7	3	70	30
Clinchfield	3	0	100	0
Danville	10	0	100	0
Franklin	3	0	100	0
Lynchburg	3	0	100	0
Monroe	2	1	66	33
Orange	3	0	100	0
Richmond	5	3	63	37
Scottsville	3	1	75	25
Suffolk	12	0	100	0
Bedford	0	2	0	100
Hopewell	0	1	0	100
Norfolk	1	5	17	83
Petersburg	12	15	44	56

95 tests made, 62 in section A = 65 per cent, 33 in section B = 35 per cent.

pH DETERMINATIONS IN THE SMALL PLANT

In view of our experience we have concluded that the present standards available on the market are not sufficiently satisfactory to warrant recommendation of their purchase and use in the smaller plants. Except under certain conditions, as previously pointed out, pH observations and calculated CO_2 are more preferable than observed CO_2 and calculated pH. The pH test is simple and rapid. The apparatus is compact and is readily transported from place to place. The chief objection to standards prepared from buffer-solutions and organic dyes is their lack of stability for a sufficient period. They are relatively expensive and the tubes fragile because of the thin tips of the ampules. In larger plants where a chemist is in charge, all objections are minimized somewhat because of the relative ease with which new standards may be prepared when necessary. In the small plant we are afraid that the failure of the standards or the loss of some of the series might lead to undesirable results or might do injury to a method with an apparent future usefulness. It is highly desirable that permanent standard

color solutions be prepared for such use. Perhaps some day the operators will be able to purchase a series of color solutions made from inorganic compounds. These solutions could be supplied in stock-bottles with each of a definite pH value. Empty tubes with stoppers furnished could be filled or refilled from the stock bottles as often as required. A broken standard tube could be then quickly replaced in the series by the operator. The organic dye solutions used as indicators in the water-sample tested are not subject to appreciable deterioration when kept in a dark cool place.

After four weeks of use by the authors a material change in certain of our pH standards has been observed. Methyl red standards lost their color completely within two weeks after purchase. The brom-thymol blue standards are more satisfactory than those prepared from phenol red. It is fortunate that the pH zone for most coagulated waters is covered by the brom-thymol blue series.

We understand that at least one investigator, Geo. C. Bunker of Panama, is working along lines toward the preparation of permanent pH standards. A great aid to all concerned will result if he is successful in producing them.

The relative ease and accuracy of pH observations and the comparative difficulty and "vanishing" end point of the CO_2 titration, together with the relative accuracy of calculated CO_2, will warrant the displacement of CO_2 titration by pH observations by many at present and by all when permanent standards are available. The value of pH observations as applied to filter plants is considerable in this one phase, even though it might never have been suggested as a means of coagulation control. Our thoughts at present are that, in the future, the operator will control coagulation through pH and alkalinity observations. If alkali is added to the filter effluent to reduce "aggressivity," then such a procedure is controlled preferably by titrating the free CO_2 and disregarding the pH and alkalinity except as a matter of interest or for investigative purposes.

The following control test is being used by certain plants in Virginia that are adding soda-ash or lime to the filtered water at a point near the pump suction.

Test: One hundred cubic centimeters of pump discharge to which 10 drops of neutral phenolpthalein solution has been added should show a slight pink cast or require not more than 4 drops (0.2 cc.) of N/22 sodium carbonate solution to produce a slight but visible pink.

Since the institution of this treatment and control a material improvement has resulted in the quality of water at the hot-water services. The limit of 2 p.p.m. CO_2 in delivered water was chosen because of practical reasons and economy of treatment. It may be permissible to allow as much as 3 or 4 parts of CO_2 in certain filtered waters without ill effect. On the other hand, we may find certain waters which will not be so satisfactory even though only 1 or 2 p.p.m. of CO_2 exists. This is a matter which requires further observation and investigation before a report of definite conclusions may be made. The operators are convinced, however, that since the application of alkali to filtered-water was begun consumers have remarked on its improved qualities. Carbon-dioxide removal by alkali has "come to stay" at these plants. As for cost, a plant reducing 6 parts of CO_2 to 2 parts in the filtered water is doing it at a cost of one quarter of a cent per 1000 gallons, where soda ash is employed. Lime would be more economical but not capable of the same ease of application and control and also a slight opalescence is apt to appear in the treated water as the result of the use of an inferior product.

In studying the alum requirements for proper coagulation in two different plants, it was possible to reduce the alkali dose in the raw water. After doing so the alum dose was lowered gradually until the minimum dose producing a satisfactory "floc" was had. In one instance the pH of the coagulated water was reduced through this procedure from pH, 7.3 (that as found) to 6.8 at which the most satisfactory coagulation resulted. In the other case the alkali was eliminated entirely from the raw-water. The alum dose was then reduced with resulting improved quality of "floc." The pH resulting after alkali elimination and alum reduction was the same as that found originally, 6.1. The latter was a highly organic water receiving aeration subsequent to alum addition.

Of economic importance is the saving at each of these plants of over $200.00 per month.

ALUMINUM COMPOUNDS IN FILTER EFFLUENTS

During the investigation no tests were made for aluminum compounds in the filtered water. It has been known to the authors since 1919 that a positive test for alumina, when using the haematoxylin or log-wood extract color tests, is obtained on many filter effluents. This is particularly true of waters which have had alkali

applied to produce a low CO_2 content prior to filtration, regardless of the point of application of the alkali. Alumina in combination will reach a minimum in effluents where the coagulation is most nearly perfect. Where the alum dose is properly controlled and added alkali is not allowed to exceed a dose sufficient to produce a coagulated-water of an alkalinity of more than 5 parts less than that of the raw water, the coagulation will be satisfactory. The colorimetric alumina test has not proved very satisfactory as a quantitative procedure. We felt that after the coagulation had been made as satisfactory as possible no considerable advantage would result from a determination of the aluminum compounds in the effluent. In this day of widespread use of aluminum cooking utensils we are wondering what ratio the aluminum eaten in food bears to the aluminum which would be obtained through the water imbibed by the same person, assuming the water to contain as much as 0.2 p.p.m. of aluminum, this quantity being the maximum ever found by one of the authors previous to this investigation in a treated water where a normal-carbonate alkalinity of 3 to 8 p.p.m. existed in the applied water at the filters.[5] Another reason for avoiding a discussion of the physiological effect of alumina in water is the following. A certain Virginia city is supplied with water purified by coagulation and settling alone. The settled water during most of the time contains traces of aluminum hydroxide and perhaps other compounds of alumina. At times of heavy draught on the plant this amounts to considerable and is visible to the naked eye. Although the water has been blamed by the medical profession for a multitude of disorders, we have not yet heard of a specific ailment

[5] Since preparing the paper for publication, George C. Bunker of the Panama Canal Zone reports to the authors the following experience: A certain plant treating a highly organic and colored water, where a normal carbonate alkalinity (pH about 8.4) has been maintained in the past in the applied water, has been found to give a filter effluent containing as much as 1 p.p.m. aluminum (equivalent to 12 p.p.m. filter alum). The alum has been completely eliminated from the effluent by the following procedure: No alkali is added after floc is formed or until the applied water has passed through the filters. Soda ash is added to the raw water prior to aeration and alum addition, in the proportion of $\frac{1}{3}$ to $\frac{1}{4}$ as much soda ash as alum required to remove the color, etc. The hydrogen ion concentration of the resulting applied water was thereby held closely to pH 6.8. The high CO_2 content was partially removed by the filters, a costly but apparently a justifiable procedure. The remaining CO_2 was absorbed by the addition of lime to the filter effluent, raising thereby the pH to 8.

attributed to the presence of aluminum, although as a general rule doctors advise use of spring-water for babies. The authors would not desire to pass on the value of a treated water containing alumina, in comparison with the famous alum-springs which are reputed to have certain therapeutic value.

CONCLUSIONS

1. The adoption of pH observations is advisable for the larger plants at present and will be for the smaller plants as soon as satisfactory permanent standards are available.

2. For practical purposes the Tillman formula may be used to calculate pH, CO_2 or alkalinity, where two factors are observed and the third is calculated. The formula does not hold when the alkalinity exceeds 65 parts for each part of free CO_2 present.

3. Satisfactory plant control may be had without direct pH observations, but observed or calculated pH will at times be of advantage and is more easily obtained by observation than by calculation.

4. Waters requiring artificial alkalinity should be carefully treated to produce an alkalinity of the coagulated water, at least 3 to 5 parts less than that of the raw later or a pH value of from 5.7 to 7, depending upon the nature of the water.

5. Carbon dioxide in treated waters should be reduced to 2 p.p.m. before pumping into mains, unless the alkalinity exceeds 100. Carbon dioxide reduction should be effected *after* filtration by aeration or by absorption by alkali.

6. Improved coagulation on certain classes of waters requires something in addition to the proper pH zone in which to coagulate. This "something" is obtained by mixing into the water, to which alum has been added, a foreign substance, preferably an insoluble finely ground material having sharp edges. Perhaps the electrical equilibrium of the colloidal phase is destroyed by the sharp edges.

7. Waters of high alkalinity possibly may be more effectively and economically coagulated if the pH is lowered through acid or CO_2 addition to the raw water simultaneously with the alum. Further investigation on this aspect is planned.

8. Waters of various bi-carbonate alkalinities and zero CO_2 will have the same pH value, which was 8.1 according to standards available.

9. Theoretical values for alkalinity, CO_2 and pH have not checked as satisfactorily with observed values at several plants as is desirable.

Further study is necessary to learn the explanation for these discrepancies.

10. A study should be made along lines of the "aggressivity" of filtered waters. Practical experiments on a larger scale than laboratory tests should be carried out to determine the maximum CO_2 content of waters of various alkalinities which will not produce "red-water" in the mains or hot-water services. The results of such a study will be of considerable practical value to water-works superintendents.

The authors have found through laboratory experiments that a certain non-organic raw-water with a pH 7.4, CO_2 of 1.5 parts and alkalinity of 26 was corrosive in the cold under atmospheric pressure. The same water after filtration and the CO_2 reduced by alkali addition to 0.5 parts, the pH raised to 7.7 and an alkalinity of 18 was also slightly corrosive. It is hoped to carry this experimental work further.

11. With improved operation, aluminum compounds need appear in few if in any filtered waters. The extent of the physiological effect of such contents is unknown.

SUMMARY

The writers have attempted an investigation to study the merits of applied pH at filter plants. As a result many interesting facts have been brought out. The facts have been presented for what they are worth with the hope that others may do likewise and mutual benefit may result therefrom. A chart for obtaining the pH of a water without the use of the pH test has been presented and its practical value demonstrated. It has been suggested that an insoluble finely ground foreign substance having sharp edges, if added in coagulation, will materially aid "floc" formation in certain waters. It has been suggested that improved coagulation of waters of high alkalinity and low CO_2 content may be had if the pH of the coagulated water is reduced through acid addition or gassing with CO_2 along with the addition of the alum dose.

A practical method of reducing "red-water" troubles has been presented.

The investigation has proved economically fruitful in reducing chemical costs at two plants.

To E. T. Cranch, of the Petersburg plant, J. H. Spurr, of the Alexandria plant and F. O. Baldwin of the Richmond plant, we are grateful for assistance given and coöperation rendered.

To Richard Messer, Chief Engineer of the Virginia State Department of Health, is due the major credit for this paper, in that it was at his suggestion that the study and investigation were made.

Correction: Formula on figure 1 should read as shown on page 379.

WATER RATES FOR INDUSTRIAL CONSUMERS[1]

By E. E. Bankson[2]

A common source of controversy, in water rate cases, is the industrial rate or rate to large consumers. On inspection of representative schedules which have been approved by courts and commissions, there is found a wide variation in attitude toward this industrial rate. The purpose of this discussion is to examine the permissible variation, in this respect, within a consistent course.

The generally accepted basis of any rate theory is that "the individual charge for service shall be equal to the cost of the individual service," although there are many cases where the decision, as to rates, has been influenced by the value or the worth of the service as indicated by competition or possible loss of business. An effort will be made first to explain or partially to define the useful scope and limitations of these two factors.

The cost basis (including depreciation and fair return) may be considered as the ideal condition serving as a guide in fixing of the rates, the magnetic pole, so to speak, toward which the rates will be drawn. They may or may not closely approach the ideal point, depending on the relative strength of opposing forces in the form of competition, etc. The embryo advocate of the "cost basis" is usually unable to recognize the justice of the "value basis" under any circumstances, apparently failing to appreciate the fact that, although we are at liberty to fix rates according to any measuring stick which seems good, we have no way of compelling the consumers to purchase at the stated price.

In general, the primary function of a water works plant is to supply water to the community, both for general and for fire protection purposes, with the industrial supply as an incidental. The reverse sometimes may be true in extreme cases. Certainly the gridiron distribution system, which is a large percentage of the total investment, as well as the fire reserve, and filter plant, if any,

[1] Read before the meeting of the Central States Section, September 27, 1921.

[2] The J. N. Chester Engineers, Pittsburgh, Pa.

are created for the community. The decision, therefore, as to the industrial supply resolves itself into the question as to whether or not this incidental supply can be sold at a profit. Mr. Chester has clearly defined a profitable or permissible rate for large consumers as "any rate which produces a result that will add to the net revenue of the plant." Coupled with this definition is also the understanding that such a rate to a large consumer should be the highest rate at which the sale can be effected; a higher rate would defeat the sale. This rate too will vary with different localities. For instance, the Pennsylvania Railroad takes its entire supply in a district from the Dennison Water Company, at approximately 10 cents per thousand gallons, while an average rate of $7\frac{1}{2}$ cents does not prove attractive to that same company in the Upper Sandusky district. The foregoing discussion does not imply that an attractive rate should be offered to all possible takers, for there would be no justice or equity in providing this incidental supply at a loss. In fact, the only justice in fixing a rate to a large consumer, which would appear lower than the rate indicated by the "cost basis," lies in the fact that the net revenue thereby obtained is to be applied in fixing a lower rate for the major supply than would be possible without the revenue from the large consumer; granting a fair return on plant investment in either case. If a manufacturing plant may easily obtain, and only requires, raw water under a low head and if the City is supplied with filtered water under a high head, the lowest rate should be made unattractive to the manufacturer, for in this case the value of the service to the manufacturing plant is lower than the minimum profitable rate to the water department or company. To supply this incidental service at an attractive rate would increase actually the burden to the domestic consumers.

Another vital point in this connection is that the attractive price to this large consumer may prove profitable only because of the existence of a surplus plant capacity, which can be used in delivering this incidental supply. This price might prove unprofitable as soon as additional capacity is made necessary. In a recent case, we protected the water company's position in this respect by indicating the low rate as applying only "so long as the present facilities of the water company are adequate." In another case where the plant capacity had been reached and where one industrial plant was taking over half the delivery at a low rate, we doubled the rate to large users, so that the rate would be in excess of the value and the large industry

would be eliminated, (or retained at a rate which would justify an increase in plant capacity).

An example of an actual case may be cited where an analysis of conditions will serve to support the foregoing statements:

A large industry in the town of "X" is now providing its own raw water supply at a cost, for 1920, of 1.6 cents per thousand gallons. It is in a position to supply the necessary filtered water for its own plant at a computed cost of 4.2 cents per thousand gallons. Allowing for contingencies, however, and for the advantages of the more reliable and carefully guarded city supply, they paid, in 1920, an average rate of $5\frac{3}{4}$ cents to the city plant for their drinking and sanitary requirements.

The rate of $5\frac{3}{4}$ cents is admittedly less than the rate which would be equitable under the "cost basis," by an impartial analysis of the annual burden obtained from the water company costs, but it is the highest rate at which the business of this industry can be retained. Because this business is retained at this rate, the fair charge to other consumers is maintained at 12 cents per thousand gallons *less* than it would be if this industrial business were lost to the water company.

On the other hand, even the out-of-pocket cost of the water company service is 2.1 cents per thousand gallons, which would be increased by necessary fixed charges on additional plant capacity if the water company should attempt to supply its filtered water to the industrial plant as a substitute for the present raw water private supply. If the water company offered a rate which would attract the entire demand of this industry, in competition with the latter's cost of 1.6 cents, there would result an increased burden on domestic consumers, provided a fair return is maintained for the water. The conclusion is evident that the lowest rate offered by the water company should be made attractive to meet the sanitary demands of the industry, but *positively unattractive* in the case of the raw water demands.

The foregoing principles applied to the majority of water rates would indicate that the value of the commodity is more compelling than the computed cost of individual service. It is to be noted, that, under a total fair return, if the industrial rate is fixed lower than the cost, the domestic rate must be fixed higher than cost, which is still within the value of the product provided the domestic consumers continue their connections. Commissions have often recognized this feature of value through their approval of rate

schedules so designed. Different phases of value have been recognized in many decisions, a few of which we quote at random:

In the Bar Harbor Power Company's case, Maine, "Rates should not be higher than the value of the service to the consumer."

In the Greenville Water Company's case, Maine, "If, in a given instance it becomes a question whether the Company shall receive an adequate return or the rates shall be just and reasonable to the customer, the company must yield to the superior rights of its customers."

In the Butte Electric Company's case, Montana, "For whatever force is given to the principle that a just rate must take account of the value of the service to the public, it cannot be said that the latter principle destroys the fair return principle, i.e., while the service may be worth nothing to the man who cannot pay, the utility cannot be compelled to meet his necessities."

In the Illinois Northern Utilities Company's case, "Gas plants, located in small communities, cannot expect rates sufficient to make them paying concerns because such rates would exceed the value of service to the consumer." Which the writer interprets to have the same meaning as expressed in the following case.

In the Lehigh Valley Transit Company's case, Pennsylvania, "There are limits of fare beyond which transportation companies cannot go without driving away their business."

The foregoing analysis indicates that *value* is the final controlling element in many cases and that an industrial rate determined by value, rather than by cost, may be good legal practice, as well as good business, as long as the existence of that rate will effect a lower rate to other consumers. The *cost* basis is the goal towards which we strive, and which in some cases may be attained.

There are instances, such as we found in the case of the City of Pittsburgh, where the most compelling influences guiding the broad and general policies of the water service are in support of, rather than against, the *cost basis* for fixing rates. For the large steel mills and furnaces, located on the river banks and requiring only raw water under a low pressure, it was clearly seen to be poor economy for them to share with the city the cost of purification, pumping over the hill tops, and finally transporting the water long distances, when a satisfactory supply is at their door at a much lower cost. It would in the end create a financial loss, for the City of Pittsburgh, to deliver water for such purposes, at a price which would prove attractive to the manufacturer so located. This is particularly the case where we discover one company pumping more water than that handled by the city plant. Years ago the city council very wisely fixed the lowest rate at a point which is unattractive to the steel

mills. Such a plan insures the City against an uneconomical increase in plant capacity.

From the foregoing discussiom the reader might erroneously infer that we are advocating the value basis as a general rule for fixing water rates to industrial consumers, but such an attitude is exactly contrary to our thought. We are pointing out rather that every case stands on its own merits. We advocate a sane, logical and consistent analysis resulting in the correct policy for each case.

The question of water rates to industrial consumers is nothing more than the question of the amount or extent of the *slide* in the meter rate schedule. On the basis of cost alone, you may find conditions supporting rates all the way from an absolute flat rate to all consumers, on the one hand, to a decided slide on the other hand.

The General Water Company, a Pennsylvania corporation, operates a water works plant which is owned and used jointly by some half dozen coal and coke companies. The water company delivers water to a central point and provides supply lines for a certain distance in any direction, at which point a large consumer desiring service, may connect and complete the line to his plant. In this case, therefore, remembering that all of the consumers are large industrials, there is no necessity for any slide in the schedule and no urgent need of any variation due to service or minimum charge.

The conditions at Milwaukee, Wisconsin, indicate a basis for rates differing only slightly from the foregoing. In this case the consumer, big or little, pays outright for his gridiron street main, individual service line, and meter, thereby eliminating from the rate base the more common causes for slide in the schedule, with the exception of the cost of meter reading, billing and collecting. This cost is covered in this case by a uniform service charge. The remaining cost consists of the uniform or flat price per thousand gallons to one and all. If it were practical to cover the service charge in the price per thousand gallons there would be created a justification for a small slide in the rate schedule.

It is the understanding of the writer that Cleveland follows practically the same policy as Milwaukee, excepting that the Cleveland water department furnishes the meter, creating a fair additional cost which, if thrown entirely into the rate per thousand gallons, would justify still more slide in the schedule than as mentioned for Milwaukee.

A practice similar to that followed by the City of Pittsburgh is next in line, which differs from Cleveland with respect to items mentioned only in that the water department furnishes also the gridiron street main. The practice in the City of Erie, where the water department provides all of these things and the individual service line in addition, justifies the greatest slide in the schedule of the entire list.

Following the case of Erie let us look at a private plant, where the Public Service Commission requires all of the items of consumer service rendered by the Erie plant, and where we are also confronted with the condition that the industrial rate be fixed on the basis of value at a lower rate than pure costs might indicate. We are justified then in a still greater slide in our schedule. More properly, a part of this slide in all cases should be covered by a service or a minimum charge.

The maximum slide in a rate schedule is justified in the case of a private plant, operating under the conditions of the case last mentioned, with the addition that there exists an excess in plant capacity which would otherwise remain idle, and where it is permissible temporarily to utilize this surplus capacity at a low rate sufficiently in excess of the cost of fuel and coagulants.

The control in these various cases might be considered as appearing on a curve or diagram, representing slide in schedule, with the general water company appearing at the bottom of the curve while at the top would be found the small private water companies giving, under Commission jurisdiction, all of the items of consumer service and under the controlling influence of the value basis, supported by an otherwise surplus plant capacity. To find the relative position, on this curve, of any plant or water company, it is necessary only to examine its characteristics and environment. In any and all cases, however, the final decision as to rates and slide in schedule should and must be based on sound and logical reasoning.

THE GOOD WILL OF THE CONSUMER[1]

MR. D. R. GWINN:[2] In our city we have tried to get the good will of the people by newspaper advertisements from time to time, by letting the public know what we are doing, by giving them the facts about the business and by telling them things that ordinarily a company would not confide to the public. Perhaps this plan helps in in two ways, for, in giving out the information the newspaper man feels a little more kindly towards the company, he has a little more softening of the heart than he would have if there were nothing coming over the counter. Our method of giving the facts to the public is to buy advertising space. I think it is a great mistake for anybody to think he can buy a paid article, booming or boosting a water company. You should do as the drygoods man does, buy space and write up the advertisement, and not depend on the newspaper man to do it for you. He does not know your game, you know it better than anyone else. Put your statement in such simple language that the public may read as it runs, use good sized type and plenty of space, a quarter or half a page. One time we had something particular to present to the public and we used two pages. It costs money, but it brings a return.

First of all, of course, it is necessary to furnish good water and good service. Do not think for a minute that you can get good publicity unless you are furnishing first class service. The public is entitled to first class service and it is a good thing, when you are furnishing it, to tell the people about it once in a while, so that they will take pride in the water supply of the city. That helps a whole lot. After you have gotten the good water and good service, then there is the office counter. You may counteract good publicity in a few minutes at the counter, by having someone there who is not considerate of the public. We have a sign in our office which reads something like this. "Courteous conduct towards patrons and the general public is a part of Terre Haute Water Service."

[1] Discussion at the Cleveland Convention, June 10, 1921.
[2] President, Water Company, Terre Haute, Indiana.

Another thing I am trying to impress on the minds of the clerks is that I am not paying their salaries. It is the people who are bringing in $1.00 or $1.25 and handing it over the counter. Be considerate of the customers. We are on the meter basis. If we find, when the readings come in, that the consumption of any particular consumer is larger than usual, we send a postal to the customer immediately and suggest that we would be glad to help him by making an inspection of his service if he so desires, and that there is no charge for service of this kind. If the consumer wants a second reading of his meter, we read it for him. We have a postal card to fill in letting him know whether the reading is correct or not. The customer will say, "Well, that water company up there is not interested in running our bills up so high and they are willing to let us know in advance of the time of delivering the bill just about how high the consumption is."

Then there is another way—getting the public down to visit the plant. We put in a tennis court and it is available to the public. They may call up the day before and register whatever hour they want to play. We maintain the court, and those who play there say it is the best in the city. When they have tournaments the finals are played on the water works court, because it is such a good court. We had a landscape gardner come and draw plans for our grounds and we have a very nice park. We invite the public to come and bring their picnic suppers and eat at our park. I recently sent out about four hundred letters, with a blue print showing the typhoid rate in Terre Haute for the last eleven years, with a note on it to the effect that as the water consumers increase, the typhoid death rate decreases. The two curves are gradually coming together. In our letter we suggest that they are interested in all the good things in Terre Haute, and so we are sending this letter to them, and suggest that when they have visitors coming to the city, to tell them about Terre Haute's good water service. We sent these out to physicians, city officials, educators and prominent people, people who make public opinion, members of the chamber of commerce, the Rotary Club, the Greater Terre Haute Club and organizations of that kind. Last year we had the Rotary Club down to our plant, for a picnic luncheon. It gave them an opportunity to see the plant, and it also gave us a chance to say a few words about the character of the service we are furnishing. We have also had the Manufacturerers' Club and the school children, and the school children are mighty good

advertisers. We get our young lady chemist to take the little girls around and show them how we make the water good. They go back then and write articles on the subject to educate father and mother, and all that helps business. You have got to be after the thing all the time to develop good publicity along the right lines.

MR. F. C. AMSBARY:[3] The purpose of our publicity campaign is not to increase our business, as it is in Mr. Gwinn's town. He told me that they had about 4600 houses on their distribution system that were not taking water, so he combined his articles for the purpose of getting good will and to sell more water. With us, our water supply is limited, and it has been our problem to get all the water we can sell. We can sell more than we are getting. I think we have the good will of the community as much as the average plant. But reading Mr. Gwinn's articles inspired me to do something along that line. We started about three or four months ago, and every week we publish, in each of the daily papers, an article on the water supply. We started out with an article headed "We Want Your Good Will." I wish I had brought it along so that I could read it to you, but it took up perhaps thirty inches of space. It was display advertising to catch the eye. We told the people that we believed if they knew more about the water works and our problems, if they knew how much money we were taking in, how much we were spending and from what source we derived our revenue and how we spent it, they would know how much we were making. If they knew more about the problems of the water supply, and its distribution and purification, that we would have their good will in a larger measure than ever before.

The next article published was a cash statement showing our revenue, how much we received from private consumers and how much from the city hydrant rental; and then we showed the expenditures. This was not a statement in much detail, but enough so that the large items were mentioned, as taxes, wages, labor, fuel, power, and it showed the revenue. We have been following that up each week with descriptions of the plant, and we always urge the people to visit the plant. I had signs painted in conspicuous letters, which read, "Visitors Welcome." I put those around on different buildings, the filter house and pumping station, and we are getting more people out to the pumping station. It is remarkable how few people visit

[3] Manager, Water Company, Champaign, Illinois.

the pumping station in our town, and I expect that applies to every city. We believe that this is going to establish us better in the community. I just heard mention of the school children. We have been having classes come there during the school year about every Saturday. We have been urging them to visit the plant through the superintendent of schools. Classes of from 20 to 40 come out and we take great pains in showing them around and explaining the process of pumping and purification. I am planning now to offer next fall a series of prizes for the best written essays on the water system of our city, to be decided by a disinterested committee.

MR. W. H. HARRISON:[4] We, not unlike the large majority of other water-works operators, are very much troubled for the fair and correct answer to claims for refunds upon large water bills. We are fully aware of the incompetency of many, and of the carelessness of more, of our public plumbers, and have tried to remedy, or at least to alleviate, the "troubles" incident thereto, by licensing and ordinance control; all of which has proven more or less ineffectual.

A large water bill accrues during the month. We immediately notify the consumer of an apparently excessive (over his general average) use of water, suggesting that he have his private plumbing looked after. The plumber is called. He repairs a small or large leak, reports everything alright to the owner, and takes his leave—(leaving, in all probability, a much worse leak behind him). The owner or consumer, assumes that his plumbing is alright and is comfortable, until shocked the following month by an even larger bill. Then the trouble commences. The consumer comes with claims for refunds, fully persuaded that his plumbing is alright, no leaks anywhere, "knows" he has not used the water, and insists that the meter is wrong, or not read, demands inspection and tests of meters, and is rarely satisfied, with all of the trouble, expense and time taken and expended by the Department, in fruitless effort towards this end.

We have printed forms for the submission of claims for refunds. One must be filled out by the owner, or consumer, and the other by the plumber making repairs.

About six or eight months ago, we added one more question to the plumbers' statement or questionnaire: "Was the meter still when you completed your work?" It has proven a "life saver," for both

[4] General Superintendent, Memphis Artesian Water Department, Memphis, Tennessee.

the Department and consumer, as it compels the plumber, after what he thinks is the completion of his work, to shut off all openings, go back and examine the meter and see if it is "still."

It was this apparently small matter that I desired to bring to the attention of the Superintendents, for what it might be worth to any who might have similar troubles of their own.

MEASUREMENT OF WATER SUPPLY BY THE PITOT TUBE IN SYRACUSE, NEW YORK

By H. R. Starbird[1]

The city of Syracuse obtains its water supply from Skaneateles Lake, situated about 19¼ miles southwest of the city, at an elevation of 465 feet above the Erie Canal. This lake covers an area of nearly 14 square miles, with a total water-shed of approximately 74 square miles, yielding an average of 55 million gallons per day. Of this, 27.5 million gallons per day is, at present, used to supply the city.

Two conduits carry the supply, by gravity, from the Lake to the distribution reservoir and stand-pipe, located in the south-westerly part of the city. The reservoir, with a water surface 245 feet below the level of the Lake has a capacity of 121 million gallons and the stand-pipe, with an overflow 109 feet above the reservoir level, has a capacity of 1¼ million gallons.

The first conduit, of cast iron pipe 30 inches in diameter, was laid in 1894, and the second one in 1908. The latter, also of cast iron pipe, is 42 inches in diameter for the first 1½ miles, with the remaining 17¾ miles of 30-inch diameter.

The distribution system of the city, consisting of nearly 240 miles of mains, ranging from 4 inches to 36 inches, is fed from the reservoir by two lines of 36-inch, and one line of 30-inch diameter pipe supplying the low service, and one line of 24 inch pipe supplying the high service section of the city from the stand-pipe.

No provision had been made, when the conduits were installed, for measuring the flow, either from the Lake or the reservoir, until 1913, when two Pitot Tube Recorders were placed on the 36-inch mains from the reservoir. Later similiar recorders were installed on the other two feed mains, and also on the two conduits entering the reservoir.

Early in 1920, it became apparent that the demand for water, during at least part of the year, would equal if not exceed the supply, and it was considered advisable to check the amount of water leaving

[1] Engineer, Bureau of Water, Syracuse, N. Y.

the Lake against that delivered to the reservoir, in order quickly to detect any considerable loss that might occur in the conduits between these points.

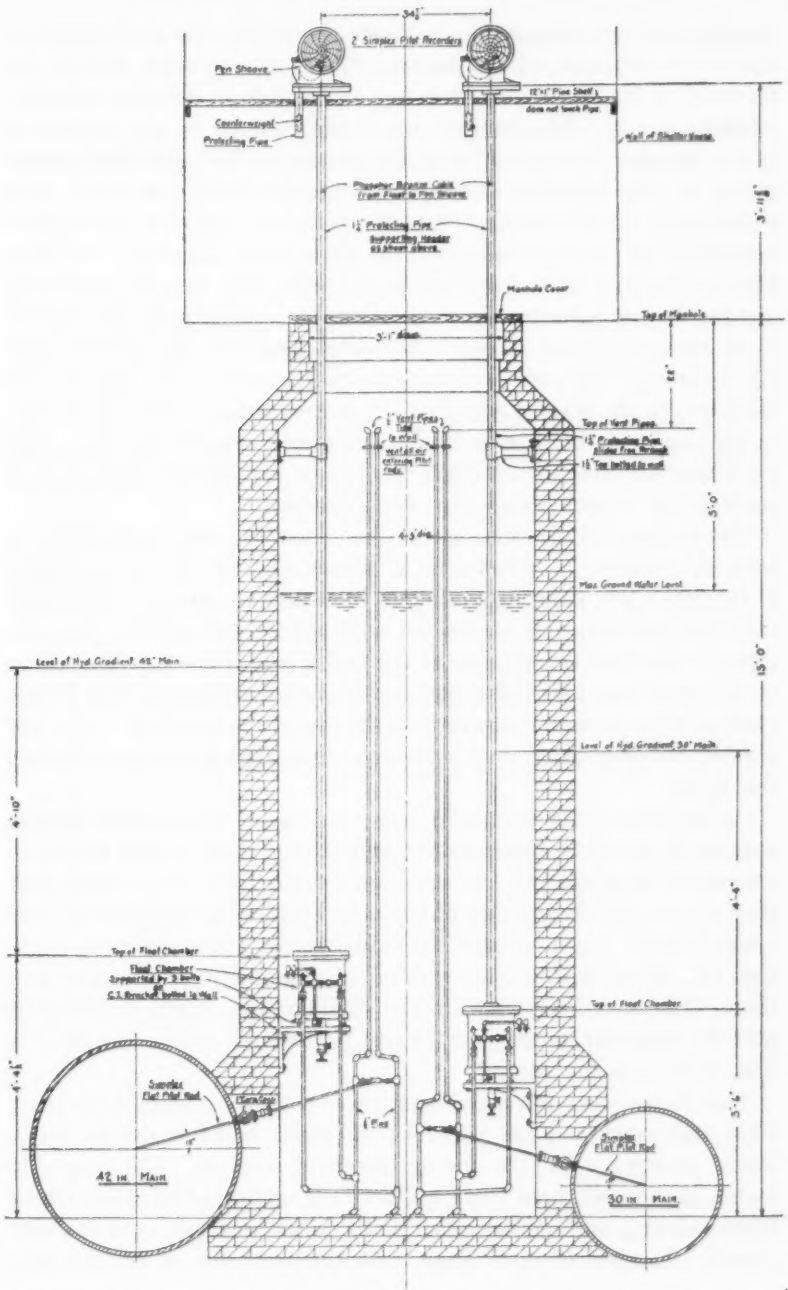
While Venturi meters are undoubtedly best adapted for measuring the flow in large mains, the impracticability of installing such meters on the conduits already laid was evident, interruption of the service being out of the question. For this reason it was decided to install Pitot Tube Recorders on the conduits at the Lake.

Four Simplex Recorders were furnished and put in place by the Simplex Valve and Meter Company of Philadelphia, two at the Lake, and two at the north gate house at the reservoir. While the installation at the reservoir presented no unusual difficulties, that at the Lake proved to be more or less out of the ordinary, and emphasizes the adaptability of the Pitot Tube for this work under unfavorable conditions. The solution of the problem seemed of sufficient interest to present to the reader.

The location selected for tapping the conduits for this installation is about five hundred feet north of the Lake, where the lines are practically parallel, and about six feet apart, on a tangent 100 feet long, making it possible to include both taps, and their float chambers, in a single manhole of reasonable size.

A brick manhole 4 feet 6 inches in diameter at the bottom, which was as large as could be built between the conduits, and about 16 feet deep was constructed, with side wells covering the mains to allow for connections, and housed over with a wooden building, 7 feet by 9 feet, to shelter the recorders. Considerable difficulty was encountered in making the excavation for this structure, on account of soft clay and quicksand, together with a large amount of percolation of ground water into the pit, making it impossible to keep the excavation open long enough to obtain a traverse on the outer tap, on the 42-inch line, which had to be abandoned. The coefficient used for this main was necessarily obtained as the result of traverses on one diameter only, making an angle of about 15 degrees with the horizontal. On the 30-inch main traverses were made on diameters 90 degrees apart, making an angle of about 15 degree from normal.

The hydraulic grade line, at this point, is approximately 7 feet 6 inches above the conduits, and the maximum ground water level about 10 feet above the bottom of the manhole. On account of slight joint leaks in the brick work in this manhole, the water normally stands at from 5 to 6 feet above the pipes. Under these



ARRANGEMENT OF SIMPLEX PITOT RECORDERS ON WATER FEED MAINS IN SYRACUSE

conditions it was impossible to locate the registering mechanism at the same elevation as the meter, which, of necessity, should be situated as far below the grade line as possible to obtain a suitable working head. The problem was readily solved by the engineers of the Simplex Company, by slight changes in their standard equipment, in the following manner. A special head was made and substituted for the regular head for the float chamber which was supported on brackets bolted to the sides of the manhole, and into this head a riser pipe, $1\frac{1}{4}$ inches in diameter, was tapped, extending upward 19 feet 6 inches above the chamber, supporting the regular head and registering device. A counterweighted phosphor-bronze cable through this pipe transmits the movement of the float in the chamber, to the sheaf controlling the recording pen. The coefficient of expansion of the pipe and cable being very nearly the same, any possibility of error in the chart reading on account of expansion or contraction in such a long pipe is eliminated.

The method of air-venting the float chamber and pitot tubes is somewhat unique, is automatic in action, and avoids the necessity of the attendant entering the pit to blow off the meters. The pitot tube was permanently connected with $\frac{1}{2}$-inch galvanized pipe, the meter connection being made at the under side of the tee connection on the pitot rod, and the upper side of the tee connected to a $\frac{1}{2}$-inch vertical pipe extending upwards to the top of the manhole. Any air that otherwise might collect in the rod automatically escapes through this vent.

On account of the unusually low head under which these meters operate, it would be reasonable to expect that these meters would be somewhat sluggish, but our experience with them has shown that they are as sensitive as any of the others which are installed on our system under much greater working heads. Repeated tests show that they check within 2 per cent of the manometer readings, at any time. The mean velocity in the 42-inch line, when discharging into the reservoir, averages 2.74 feet per second, and in the 30-inch line, 4.93 feet per second.

This Bureau now owns and operates nine Simplex Pitot Recorders, eight stationary and one portable, the latter being in use on water waste surveys. All are giving excellent service. The portable meter, in the past three years, has seen a good deal of hard service on these surveys, and has travelled many miles by truck over the city streets. In spite of such usage, with the exception of several acci-

dents, it has cost practically nothing for maintenance. During this period, over 5½ million gallons per day of waste or leakage have been detected by means of this meter.

The original installation of Simplex Recorders in this city proved conclusively the accuracy and reliability of such instruments. This meter was connected to the 24-inch high service feed main from the standpipe, the tap being located a few feet from the outlet valve, giving a somewhat unusual opportunity to check its performance, by comparing the drop in the standpipe, over a fixed time, with the chart readings. The results of this test, as shown below, demonstrate the accuracy of measurement of flow by means of Pitot Tube Recorders.

ELEVATION OF WATER IN STAND PIPE	DROP OF WATER LEVEL	DURATION	AVERAGE RATE OF FLOW PER 24 HOURS		PER CENT ERROR	AVERAGE VELOCITY FEET PER SEC.
			By stand-pipe	By Simplex recorder		
feet	*feet*	*hours*	*gallons*	*gallons*		
72.83						
	10.69	8	822,000	811,000	−1.25	0.512
62.14						
71.19						
	7.05	3	1,445,000	1,439,000	−0.45	0.909
64.14						
69.75						
	7.08	2¾	1,583,000	1,588,000	+0.40	1.745
62.67						
71.19						
	21.40	4¾	2,765,000	2,780,000	+0.40	1.000
49.79						
60.58						
	10.79	1¾	5,300,000	5,300,000	0.00	3.350
49.79						

THE SOLUTION OF CORROSION AND COAGULATION PROBLEMS AT MONTEBELLO FILTERS, BALTIMORE

By John R. Baylis[1]

Water which is corrosive to iron pipes is found in the supplies of a great many of our cities and is frequently the cause of numerous complaints. Many supplies originally not corrosive to an objectionable extent have been made so by chemical treatment, especially where alum is used as a coagulant. The most corrosive water is usually one whose hardness is below 100 p.p.m., and, in some instances when it is very low, it is necessary to use an alkali to reduce corrosion.

Efforts are being made at Baltimore to reduce the corrosion to a point where there are no complaints. The supply is obtained from the Gunpowder River and is filtered at Montebello Filters. Alum is used as a coagulant and lime is applied after filtration, unless occasionally a small amount is needed to produce a pH value sufficient for good coagulation.

The alkalinity of the water before treatment averages about 37 p.p.m., with a minimum of about 20 when the water is very turbid. The total hardness is about 42 p.p.m., and the free carbonic acid averages 5 p.p.m. The average amount of alum used is 1.2 grains per gallon, and, when applied at the average rate, reduces the alkalinity 8 to 10 p.p.m. and increases the free carbonic acid 5 to 10 p.p.m. The maximum application of alum is about 3.5 g.p.g. for very turbid water, which reduces the alkalinity about 27 p.p.m., and increases the free carbonic acid above 20 p.p.m.

The pH value before treatment averages 7 and is reduced to between 6 and 6.5 when the average amount of alum is added, and below 5 when the maximum amount is used. The terms increase and decrease in pH apply to the figures, which are the logs of the reciprocal of the hydrogen-ion concentration. Five is below the value necessary to obtain good coagulation, so at such times an alkali is applied near the same point as the alum.

[1] Principal Sanitary Chemist, Montebello Filters, Baltimore, Maryland.

Since the filter plant was put in operation in 1915 and until 1918, iron and lime were used exclusively as coagulants, but since the latter period alum has been used part of the time in 1918, most of the time in 1919, and now all of the time. When iron and lime were used, good coagulation was hard to obtain unless the amount of lime used was high, so it was applied most of the time in quantities sufficient to give after filtration a monocarbonate alkalininity above 10 p.p.m. and a pH value from 9 to 9.5. This procedure resulted in encrusting the sand grains in the filter beds, greatly increasing their size, and encrusting slightly the pipes in the distribution system. Except for hot water pipes the corrosion was slight, although a heavy dose of chlorine increased it somewhat. Complaints of "red water" during this time were few and were confined almost entirely to hot water pipes.

Difficulty in obtaining satisfactory results when iron and lime were used, due partly to the character of the water and partly to insufficient time in the mixing basin, brought about a change to alum. This change resulted also in a lower cost for coagulant, as the alum was more effective and could be used in much smaller quantities, the ratio being about two to one.

When it was first used the incrustation on the sand grains in the filter beds, consisting mostly of carbonate of lime, reduced the free carbonic acid to about 1 p.p.m. There was very little increase in corrosion for some time, but by the latter part of 1919 most of the incrustation had dissolved from the sand grains and the free carbonic acid increased above that in the raw water. There was an increase in the iron contents of the water passing through the distribution system, and soon complaints from "red water" became very frequent.

Since October, 1919, lime to reduce corrosion has been used almost continuously. This method brought about other difficulties. Alum reacts best with a bicarbonate alkalinity. The application of lime, therefore, at approximately the same time as the alum greatly increased the amount of alum necessary to form good coagulation. Actual results compare fairly closely with experiments conducted at Jackson, Miss., in 1915 and 1916, on the effect of adding lime before alum.[2] No provision was made in construction for the application of lime at any point other that at the entrance to the mixing basin. Recommendations advising the application of lime after the water

[2] Engineering News-Record, Vol. 80, February 21, 1918, page 364.

has passed through the coagulating basins and just before filtration were made, but instead of applying at the point recommended it was applied at the end of the mixing basin just before the water passes to the coagulating basins. This was a great improvement over the other point of application, but it was still found impossible to add enough lime at this point to reduce corrosion to the desired point, without increasing the amount of alum. It was also found that coagulation perfectly formed is partly redissolved by the addition of lime in small quantities. When the water was very turbid, requiring the use of from 2 to 3 g.p.g. alum, lime greatly affected the coagulation, if enough was added to reduce the free carbonic acid to nearly the neutral point. Consequently at times of high turbidity the lime was not increased in the same proportion as the alum, so the water was frequently very corrosive and caused complaints.

In table 1 are shown the results of a few tests made to determine the amount of aluminum hydroxide dissolved by the application of lime at the outlet of the mixing basin, which is after the floc has been formed. Samples of filtered water from the two filter galleries were filtered through No. 40 Whatman's filter paper, one or two liters evaporated to dryness, and the iron and aluminum oxide determined gravimetrically No attempt was made to determine the iron oxide, but it averaged only about 0.2 p.p.m. in the combined filtered water and if most of it came from the north gallery it would not affect the results materially One grain per gallon of alum gives about 2.6 p.p.m. aluminum oxide (Al_2O_3), so these tests indicate that there is more aluminum oxide in the water from the north gallery, which is water that receives most of the lime, than was being applied. This is possibly due to aluminum compounds naturally in the water. Gravimetric determinations of the aluminum oxide in the composite monthly samples for August and September, after being filtered through alundum crucibles, average 1.5 p.p.m. The alumina in the filtered water is partly that naturally in the water and partly dissolved from the aluminum hydroxide. Lime was applied where it received only a partial mix in going to no. 1 settling basin, so some of the aluminum hydroxide was in contact with highly caustic water for a short time. It is safe to say that one-half of the floc in this basin was dissolved at times by application of lime at the outlet of the mixing basin.

The hydrogen-ion concentration determinations seem to offer a better indication of the corrosive qualities of water than other current

TABLE 1

Showing soluble iron and aluminum oxide in filtered water. All samples filtered through No. 40 Whatman filter paper: Gravimetric Determinations of Al_2O_3 and Fe_2O_3

DATE	TURBIDITY	GRAINS PER GALLON ALUM	ALKALINITY			FREE CARBONIC ACID			MONOCARBONATE ALKALINITY			pH			IRON AND ALUMINUM OXIDE P. P. M. Al_2O_3 AND Fe_2O_3		
			Mixing basin	North gallery	South gallery	Mixing basin	North gallery	South gallery	Mixing basin	North gallery	South gallery	Mixing basin	North gallery	South gallery	North gallery	South gallery	Mixing basin
1931																	
August 19	60	1.25											8.4	7.9	6.0	2.5	
August 22	88	1.25		47	40		1.8	4.0	0.0	0.0	0.0		7.8	7.2	4.1	1.7	
August 29	25	0.67		56	51		0.0	1.3		6.0	0.0		8.5	7.8	3.4	1.5	
August 30	23	0.60		54	51		0.0	1.7		4.0	0.0		8.4	7.7	3.0	2.2	
August 31	23	0.60		56	51		0.0	1.7		3.0	0.0		8.5	7.6	5.0	2.8	
September 1	23	0.55		53	48		0.0	3.1		2.0	0.0		8.4	7.5	3.4	1.4	
September 2	20	0.55		55	49		0.0	4.4		1.0	0.0		8.4	7.3	4.6	1.0	
September 16	140	1.82	19	34	28	20.7	4.8	9.7	0.0	0.0	0.0	6.0−	7.1	6.7	2.2	1.4	3.2
September 19	70	1.66	15	39	30	28.6	3.1	8.0	0.0	0.0	0.0	6.0−	7.5	6.7	2.4	1.6	1.0
September 30	60	0.64	37	49	45	10.6	6.0	4.0	0.0	3.0	0.0	6.7	8.4	7.4	3.7	1.6	1.2
Average.....	53	0.96	24	49	44	20.0	1.1	4.2	0.0	2.1	0.0	6.2−	8.1	7.4	3.8	1.8	1.8

Note: Lime is added to water at outlet of mixing basin, and does not mix thoroughly before it divides to go to the two settling basins. Consequently more lime goes to No. 1 settling basin than to No. 2. The effluent of the two basins are connected, but most of the water supplied the filters in the north gallery comes from basin No. 1, and the south gallery from basin No. 2. Mixing basin samples are before lime is added. Fe_2O_3 averages about 0.2 p.p.m. One litre samples from 8–19 to 9–2; two litre samples from 9–16 to 9–30.

tests. For some time, therefore, we have been trying to find a concentration that will be most suitable for the water supplied to Baltimore City. A hardness of 50 p.p.m., which is about the average of that supplied to the city, requires a pH value of about 8, in order to reduce corrosion in cold water pipes to a point where there will be practically no complaints. Realizing that complaints are made only when corrosion is fairly rapid, a pH value of from 8.5 to 9 has been tentatively set as that desired. The indications are that 8.5 is sufficient. Harder water may have a pH value lower than this, and for very hard water it may be about 7 without danger of excessive corrosion.

In the attempt to keep the water near the desired pH value, it was soon realized that some other point of application of the lime was necessary. Experiments on dissolving aluminum hydroxide with an alkali clearly indicated that the proper point of application was after filtration, and not before, as formerly recommended. Changes have been made in the lime pipe lines so as to apply it at this point. Evidence to date in handling a very variable character of water clearly indicates that this is the proper point to apply an alkali to reduce corrosion when alum is used as a coagulant. It is necessary to use some alkali to create proper coagulation, if the pH value goes below a certain point, which has been found to be about 5.5 for the water here under discussion. Almost complete precipitation is obtained when the pH is between 6 and 7, and fairly good when between 5.5 and 6, so no lime is applied at the entrance to the mixing basin unless the pH value goes below 5.5 after the application of alum, and then only enough to bring it to approximately this value. A greater amount causes an increase in the amount of alum necessary. We have no data on precipitation for values above 7, except experimental, as our raw water never goes above 7.4. When alum is applied in minimum amounts (0.4 grain per gallon) it reduces the pH to about 7. Added alkalinity, if bicarbonate, indicates that good precipitation can be obtained when the pH is considerably above 7.

Recent observations on the causes of turbid water passing the filters, and their correction are typical of conditions that have happened a number of times since alum has been used as a coagulant. These will give some indication of the importance of pH values in coagulation.

February 6, 1922. Raw water: turbidity 230, alkalinity 23, free carbonic acid 5 and pH 6.8; 2.5 grains per gallon alum applied, and after passing through mixing basin with about one-half hour mix

contained: alkalinity 8, free carbonic acid 26.0 and pH 5.1. Coagulation was imperfect and turbidity after filtration was 5. Samples collected from outlet of mixing basin settled fairly rapid to a turbidity of about 10, then no appreciable change in seven hours. After settling over night the pH changed to 5.7, coagulated during the night and sedimentation was complete the next morning. As soon as the pH was found to be low the alum was reduced to 2 grains per gallon resulting in some improvement. The application of a small amount of lime to increase the pH to 5.6 helped considerably and results were very good but not perfect. Due to the turbidity and the effect of lime on the amount of alum necessary for coagulation, 2 grains per gallon was not enough and samples settling over night did not show perfect, nor any improvement after standing forty-eight hours, when they were discarded. A sample treated in the laboratory with 2 grains per gallon alum and stirred thirty minutes showed very good floc and settled rapidly to a turbidity of 8 in two hours, pH 5.4. No change in seven hours, but standing over night pH changed to 5.6, coagulation perfect and sedimentation complete. Laboratory sample treated with 1.5 grains per gallon alum and stirred thirty minutes showed perfect coagulation and complete sedimentation in two hours. The alum applied in the plant was reduced to 1.5 grains per gallon and the addition of lime with the alum stopped. Water thus treated showed good coagulation and filtered perfectly.

February 11, 1922. Raw water: turbidity 120, alkalinity 22, free carbonic acid 5 and pH 6.9; 1.82 grain per gallon alum produced very poor results, filter effluent having a turbidity of 4. Samples of effluent from the mixing basin showed: alkalinity 7, free carbonic acid 38.3 (very high but checked by several samples), pH 5.2. Settled to turbidity of 8 in two hours and showed no further change in seven hours. Settling twenty-four hours pH changed to 6, coagulation became perfect and settled completely. Alum reduced to 1.34 grain per gallon which showed an alkalinity of 15 and pH 6.5. Coagulation complete and filtered perfectly. Laboratory sample treated with 1 grain per gallon alum and stirred twenty minutes produced a good floc that settled rapidly to turbidity of 3. No change in forty-eight hours showed that this amount of alum was insufficient for proper coagulation.

These, and other results not reported here, show that the pH value should not go below 5.5 for good coagulation, and demonstrate also the advantage of pH values over alkalinity in determining if an

alkali is needed with the alum. During only a very small per cent of the time at Baltimore is the pH reduced below 5.5 after the application of alum, but there are a number of cities treating water for filtration where the pH is reduced below this figure for a large percent of the time. Large plants with close supervision can adjust their waters to any desired hydrogen-ion concentration, but small plants with no chemist in charge may have some difficulty in producing good results. Possibly the best plan is to do as the author did a few years ago at Jackson, Miss. The settling basins were used in series and the lime was applied at the point where the water passed from one to the other. Most of the floc settled in the first basin, but frequently the water had a milky look before the lime was applied. At such times the water coagulated again in the second basin when lime was used. With our present knowledge of hydrogen-ions best results may possibly be obtained at this plant by applying a small amount of lime at approximately the same point as the alum to produce a pH of about 5.5 and applying the balance after filtration to prevent corrosion.

THE USE OF LIME TO PREVENT CORROSION

Many cities desire to prevent corrosion, yet it is surprising how few make any conscious attempt to do so. If iron and lime are used as coagulants it is necessary to have a high pH value (8.5 to 9.5) to produce good coagulation, so where these chemicals are used there are few complaints of corrosion. Iron is not suitable for all kinds of water, especially when highly colored, so alum will continue probably to be a most widely used coagulant. When used with soft water it will cause considerable corrosion of the service pipes, which can, and should be, reduced in many instances. The difficulties heretofore experienced in trying to use an alakli with alum has delayed its application in many instances, but with our present knowledge of coagulation processes it should become more extensively applied.

Considerable study has been given to the degree of corrosion causing complaints and its prevention. Extensive experiments were conducted to determine the total corrosive qualities of the Baltimore water supply, but not much of practical value was learned. It was shown that all the waters used attack pure iron with a bright surface very rapidly. Water with a pH of 5 attacked the entire surface, whereas that with a value of 9 corroded only in spots. The dissolved

oxygen determines the total corrosion possible. If this were all used up in the Baltimore supply the life of iron pipes would be very short, possibly less than two years for wrought iron service pipes. The total corrosion possible is about 300 pounds of iron for each million gallons of water, or about 10,000,000 pounds yearly. With a bright surface exposed in 1½-inch wrought iron pipe, the iron contents of the water was increased about 15 p.p.m. in thirty minutes. This result shows the experiments on iron having a bright surface exposed are practically worthless. It is the rate of corrosion in service pipes, with partially protective coating, that concerns the water works official. The protective coating may be one applied by the manufacturer or it may be formed by the water passing through. Artificially applied coatings eventually wear off or dissolve from the pipes and protection then depends on the coating naturally formed.

To form some idea of the rate of corrosion taking place in the water pipes of Baltimore, daily tests have been made of the iron contents of the water leaving the filter plant and of that in the laboratory tap, which is water that has passed through several miles of cast iron mains. This sample gives possibly a fair idea of the total time of travel in the mains. The difference in iron between the two samples is a fair average of that going into solution or in suspension. How much remains as scale we are unable to tell, but it is possibly less than half of the above amount.

Comparison of iron, carbonic acid and dissolved oxygen in filtered water, p.p.m.

YEAR	IRON (Fe)		INCREASE IN IRON	FREE CO_2 FILTERED WATER	DISSOLVED OXYGEN
	Filtered	Laboratory tap			
1919	0.07	0.15	0.07	4.0	7.8
1920	0.10	0.21	0.11	6.6	7.8
1921	0.14	0.25	0.11	5.0	7.2

A study of the records indicates that, had no lime been applied, the iron contents would have been increased about 0.30 p.p.m. in passing through the cast iron mains. A large portion of the water passes through the wrought iron service pipes, which are more readily attacked, so that the actual increase in iron is greater than the laboratory sample shows. The total corrosion including the scale adhering to the pipes is estimated at 0.60 p.p.m. when lime is not used. The amount of water passing through the distribution system has aver-

aged about 100,000,000 gallons daily for the past four years, so the total corrosion would be about 500 pounds daily if no lime were used. Leaks, damages to pavements and buildings, and cost of repairs, amount to a great deal per pound of pipe replaced. It may amount to as much as fifty cents per pound in some cities.

The use of 0.39 grain per gallon of lime, costing about $25.00 per day in 1921, reduced the corrosion to a total of approximately 0.22 p.p.m. The application of the lime after filtration as is now being done, to give a pH between 8.5 and 9, requires about 0.55 grain per gallon, costing about $35.00 per day. The total corrosion is reduced to at least 0.10 p.p.m., showing that the saving in piping is worth considerably more than the cost of lime used. Besides this procedure produces more palatable water. It has the disadvantage of making the water harder, requiring the use of more soap. Whipple, in "The Value of Pure Water," estimates that each person completely softens one gallon of water daily. Assuming that we have progressed somewhat in cleanliness, it is safe to estimate that 1,000,000 gallons is softened in Baltimore daily. The increase in soap hardness is about 10 p.p.m., which increases the amount of soap used about 2000 pounds per day, basing the estimate on laundry soap. The increase in cost of soap and the cost of lime may be somewhat greater than the value of the iron saved, but satisfaction has a value that will more than offset this difference, if there is any. If there were no depreciation in the pipes, water departments would be justified in preventing "red water." In Baltimore the total added cost for lime, soap, etc., amounts to only about 15 cents per year for each inhabitant. Comparing this with the amount we spend for satisfaction in food and clothes, it amounts to practically nothing.

The increase in iron contents of the water passing through the pipes is now kept at about 0.05 p.p.m., and represents a total corrosion of not over 0.10 p.p.m. for the amount consumed. Complaints from "red water" have ceased almost entirely. The ideal point is possibly where the tendency to encrust and corrode are at a minimum. Since we have found the pH value of this point to be about 8.5 for the water supplied to Baltimore, we have no difficulty in keeping corrosion reduced to a low rate.

METHOD OF MAKING PH DETERMINATIONS AT MONTEBELLO

Color standards are used in making the pH determinations. These standards are prepared according to the method recommended

by Clark and Lubs, and sealed in 15 x 100 mm. pyrex tubes. These tubes are thoroughly cleaned, drawn at the top, filled with 10 cc. of the standard, and sealed. Standards are made for each 0.2 pH variation from 5.2 to 9.6. Brom-cresol purple (5.2–6.6), brom-thymol blue (6.2–7.4), phenol red (7.0–8.4) and thymol blue (8.2–9.6) are the indicators used. Solutions are made the strength recommended, and 0.5-cc. quantities are used both in the standards and the samples.

Sample bottles are thoroughly rinsed with water the same as the sample, then the sample collected and tested immediately. A tube the same size as the standard is thoroughly rinsed with the sample. A thoroughly cleaned 10-cc. pipette is filled with the sample, discarded, and another 10-cc. portion withdrawn and put in the tube. Five tenths cubic centimeters of the indicator is added to the tube, mixed, and a comparison made. Results are recorded to the nearest 0.1 pH value.

For clear solutions, or when slightly turbid, comparisons are made by holding the tubes against a white piece of paper. For accurate results a comparator block should be used if the turbidity is over 20, though fairly accurate results can be obtained with turbidities as high as 100.

The standards are kept in a dark room, except for a few minutes when in use. They are checked every two months, and if any show variations, they are replaced.

CLEVELAND WATER SYSTEM[1]

By G. E. Flower[2]

LOCATION AND SOURCE OF SUPPLY

The city of Cleveland is situated on the southern coast line of Lake Erie about one-third of the way from Toledo to Buffalo. The indentation, or bay, is about 40 miles long measured from Avon Point to Fairport and about 7 miles wide. The city is located at the deepest point of the indentation. The water within the bay is nowhere deeper than 60 feet and its average depth may be taken roughly as 50 feet. The bottom is chiefly fine sand and clay, but in some places there are deposits of mud, and in a few spots the bottom is rocky. Lake Erie is the fourth in the chain of Great Lakes. At its west end it receives, through the Detroit River, the water of Lake St. Clair, Lake Huron, Lake Michigan and Lake Superior; at its easterly end the water discharges through the Niagara River and over Niagara Falls into Lake Ontario and thence into the St. Lawrence River. The lake has a length of about 250 miles, measured on a median line between the inlet and the outlet. Its greatest width is nearly 60 miles, and its average width, except at the extreme ends is about 45 miles. The surface area of Lake Erie is a little less than 10,000 square miles. The average depth is about 63 feet and its capacity is about 17,500,000 million cubic feet. The foregoing is a general description of Lake Erie, which our forefathers after much thought and consideration, decided upon as a source of supply for water.

GROWTH OF WATER WORKS

Before the water works was started and while Cleveland was just a small village, water was obtained from springs and wells. There was a good spring on the square where the old court house now stands, and also a spring of soft water on Superior Avenue near the entrance of the Old Arcade. Most of the spring water was hard and

[1] Presented at the Cleveland Convention, June 7, 1921.

[2] Sanitary Engineer, Water Department, Cleveland, Ohio.

water for washing purposes was hauled up the hill from the river in barrels and wagons.

In 1854 work was started on the first pumping station. It drew its water from Lake Erie. On September 19, 1856, water was pumped into the mains, and was the cause of much jollification and celebration. The pumping equipment consisted of two Cornish beam engines and six boilers. The inlet was a pipe made of boiler plate 50 inches in diameter, extending 300 feet from shore, and 400 feet west of the western terminus of the old river bed, and into 12 feet of water. This distribution system in 1857 consisted of 13 miles of pipe mains and one reservoir of 6,000,000 gallons capacity. In 1920 the distribution system had increased to 1452 miles of pipe and four reservoirs with a combined capacity of about 157 million gallons. The average daily pumpage in 1857 was 348,700 gallons and in 1920 140,337,000 gallons.

The record shows that the number of connections with meters in 1874 was 1.28 per cent of the total number of connections. This percentage gradually increased until in 1901, it was 6.42 per cent. In 1902 the policy of metering all connections was inaugurated, so by the end of the year, 19.88 per cent of the services were metered. This policy was steadily followed until in the year 1909 practically 100 per cent of the entire supply was measured through meters.

The operation of the Cleveland water supply system may be best compared with the human body, the pumping station forming the heart of the system and the distributing pipes the veins and arteries, with the filtration plant as an added safeguard to the health of the cummunity.

Water is obtained from Lake Erie from a point some distance from the shore and is conveyed to the pumping stations by tunnels, a 9-foot tunnel to Kirtland station, located at the foot of East Forty-ninth Street and a 10-foot concrete block tunnel which divides into a 5-foot and a 7-foot tunnel, about a mile from shore, which supplies the Division pumping station located at Division Avenue and West Forty-fifth Street.

The inlets in the lake are protected by cribs, whose function is to keep out any floating logs or debris which might otherwise enter the tunnel and cause serious damage. The east side crib or intake is visible from shore, extending above the lake level, while the west side intake is submerged about 35 feet below the surface of the lake, which

does away with the necessity of keeping a watchman and a light on it for protection of passing ships.

After the water reaches the shore through the tunnel it enters what is known as a screen chamber in which several screens are suspended. These screens catch all matter which passed the protection at the intake, such as sticks, leaves, fish, etc. There are two sets of screens of ½-inch mesh in the screen well, so one set may be kept in and the other removed for cleaning. From this point on, the operation of the Division and Kirtland stations is somewhat different due to the location of the filter plant at Division Avenue.

METHOD OF HANDLING THE WATER AT KIRTLAND STREET PUMPING STATION

The water after it passes the screen well flows to pump wells, one for each pump, which act as a reservoir for the pump suction. The distributing pumps, of which there are five of 130,000 million gallons a day capacity, take the water direct from those wells and pump it into the system. Steam for running the pumps is generated by eight boilers. The coal is delivered to the station on an overhead track and dumped directly into the storage bins. Up to September 11, 1911, the water was pumped into the mains without any treatment, but on that date an apparatus was installed for the application of calcium hypochlorite. This method of treatment was used, except for a short period in 1916, when an electrolyzed salt solution was applied in place of the bleaching powder, until the installtion of Wallace and Tiernan liquid chlorine machines, on July 16, 1917. These are still in operation at the pumping station. The chlorine is not "shoveled into the water" as some people imagine, but is accurately and closely controlled by sensitive valves and scales.

FILTRATION PLANT AT DIVISION AVENUE

The water is drawn from the tunnel through the screens located in the screen well and is forced by turbine driven centrifugal pumps to the filter plant. There are three low lift filter plant supply pumps, two capable of pumping 100,000,000 apiece and one capable of pumping 60,000,000 gallons of water a day. The water is forced by these pumps through a 72-inch riveted steel pipe to the mixing chambers from where it flows by gravity. As the water passes through the chemical house on its way to the mixing chambers it is measured by

a large 72 by 42 inches Venturi meter. This affords the men in charge an opportunity of regulating the amounts of chemicals to be added to the water.

Chemical House. The chemicals are shipped in box cars onto a railroad track alongside of the chemical house where they are unloaded by scoop-shovels into a chute through a crusher, of the flail type, to a bucket elevator. The latter elevates the chemical to the top floor of the chemical house into a worm conveyor, which conveys it to separate storage bins. The are eight lime or aluminum sulphate storage bins of 1500 tons total capacity, and two iron sulphate storage bins of 400 tons total capacity.

The chemicals are taken from the bins through the chutes to the different scales. After leaving the scales, the chemicals drop into the slaking tanks and solution tanks where they are put into solution. The solution is forced into the water by six Penberthy water injectors.

Mixing chambers. The water passes from the chemical house into four mixing chambers where the water is agitated, causing the water and the chemicals to become thoroughly mixed. This mixing is done by forcing the water over and under wooden baffles, and also back and forth through narrow channels. The agitation period in the mixing chambers varies from ½ to 1 hour. The water then flows into the settling basins.

Settling or coagulation basins. There are six basins, each holding about 3,500,000 gallons. Each basin is divided into three compartments. The water flows down one compartment and around the end of a baffle back through the middle compartment around the end of a second baffle and then through the third compartment over a skimming weir into a long gallery. The water flows from here through four 48-inch cast iron pipes to the filters.

During the period of three and one-half to four and one-half hours in the settling basins about 75 per cent of the suspended matter and a certain proportion of the bacteria are precipitated. Each settling basin and mixing chamber is independent of the other and may be shut off, drained and cleaned by flushing. Cleaning is done about once a year.

Filters. The water flows from the settling basins to the filters and then to the clear water basin.

There are 36 filter units equipped with the usual recording and regulating devices. Each filter has an operating table, which is used in operating the five hydraulic valves connected to the filter. Each

filter has 27 inches of quartz sand of 0.45 mm., effective size and 22 inches of graded gravel, the latter ranging in size from one and one-half inches to the coarse sand at the bottom of the sand layer. The average period of service for each filter is about thirty hours. The actual time of washing is about three minutes. The filtered water leaves the filter through a concrete twin conduit leading to the filtered water reservoir, where there is applied one pound of liquid chlorine per million gallons of water, for disinfection purposes.

Laboratory. At the Division Avenue filtration plant, samples are taken three times daily of the raw, settled, filtered and disinfected water and once a day at the Kirtland Street pumping station of the raw and disinfected water. From these samples, bacteria and chemical tests are made which enable the operator to have scientific control of the operation. The Division of Water has one of the best equipped laboratories in the country for water, oil, coal and cement testing.

GENERAL FILTER PLANT DATA

Capacity 150,000,000 gallons per twenty-four hours.

Coagulants used: Lime (CaO)—0.6 grain per gallon; sulphate of iron ($FeSO_4 \cdot 7H_2O$)—0.8 grain per gallon; sulphate of alumina $Al_2(SO_4)_3 \cdot 18\ H_2O$,—0.8 grain per gallon.

Mixing period—forty-five minutes.

Settling period—four hours.

Number of filters—36.

Capacity of each filter—$4\frac{1}{6}$ million gallons per twenty-four hours.

Rate of filtration 125,000,000 gallons per acre per day.

Rate of wash, 20 gallons per square foot per minute.

Area of each filter, 1454 square feet.

Filtered water reservoir, 20,000,000 gallons capacity.

Area occupied—20 acres.

Total excavation—640,000 cubic yards.

Total concrete placed—125,000 cubic yards.

Original cost (exclusive of land): Filtration plant, $2,225,000; pumping station, $1,220,000; crib and tunnel, extension, $1,200,000; total, $4,645,000.

Cost of filtration per million gallons of water for 1920: Operation, supervision, labor and supplies, $2.22; chemicals $1.45; labor and material for maintenance, $0.80; total $4.47.

The large triple expansion pumps which pump the water to the distributing system about the city are located at the pumping station.

They draw the water from the filtered water reservoir and pump it under pressure into the mains and reservoirs located in other parts of the city. There are six pumps at Division pumping station, two, having a combined capacity of 30,000,000 gallons daily, pump into the first high service territory and four, having a combined capacity of 90,000,000 gallons a day, pump into the low service territory. There is now in course of construction one 20,000,000 turbine driven centrifugal to be used for the first high service territory. Steam for operating these pumps and the low lift pumps is generated in six 500-h.p. boilers. Coal is handled by conveyors and elevators and stored into bins. All the water used in boilers is metered and the coal is weighed at each boiler by automatic scales.

RESERVOIRS

There are five storage, or equalizing reservoirs, that equalize the pressures in the separate districts and also serve as sources of supply for other services.

Fairmount reservoir, with a capacity of 80,448,400 gallons, consists of two basins and is used for supplying the low service districts and also used as a source of supply for the pumps at Fairmount pumping station, to pump the water into first and second high service.

Kinsman reservoir, with a capacity of 35,219,700 gallons, is the supply for the first high service district.

Warrensville reservoir, with a capacity of 22,250,000 gallons, is the supply for the second high service district, and is used as a source of supply for the pumps at Warrensville pumping station for the third high service district.

The steel tower holding 200,000 gallons is used for the third high service district.

The clear water reservoir is the suction well for the vertical, triple expansion pumps located at Division Avenue pumping station, which pumps the filtered water into the service.

DISTRIBUTION SERVICE

Due to the natural topography of the city of Cleveland and adjacent towns which it supplies with water, the distributing system is divided into four different territories known as low, first high, second high and third high services. The low service district, the largest, takes in all teritory that lies between city datum and 120 feet above

it. City datum is 2.34 feet above average lake level. First high service district embraces the territory between 120 and 250 feet above city datum, second high service between 250 and 500 feet above city datum and third high service over 500 feet above city datum.

River tunnels. In order to facilitate easy accessibility in case of leaks in the water mains that carry the water from one side of the Cuyahoga River to the other, five tunnels were driven under the river. They were placed at sufficient depth below the bottom of the river so that there is no danger of breakage. The five river tunnels are located as follows:

St. Clair Avenue tunnel, 7½ feet in diameter, completed in May, 1891.

Clark Avenue tunnel, 8 feet in diameter, completed in July, 1895.

Main Street tunnel, 8 feet in diameter, completed March, 1897.

Superior Avenue tunnel, 8 feet in diameter, completed in December, 1897.

Central Avenue tunnel, 10 feet in diameter, completed in July, 1916.

Pipe distribution system. The sizes of water mains range from 3 inches to 48 inches in diameter. Fire hydrants are placed at intervals of about 300 feet. The general rule is to lay the pipes at least 6 feet deep, but this cannot always be followed. The service connections are lead pipe up to 1 inch size, wrought iron pipe from 1 inch to 3 inch size and above 3 inch size cast iron pipe. Stop cocks enclosed in a cast iron box are placed 1 foot inside the curb on all service connections up to 3 inch size, and from 3 inch up to 6 inch size, are usually placed about two feet from the main. Gate valves are so placed that if there is a break in the main, the break can be isosolated by closing a few valves. During the repair work the water is diverted so that as small as number as possible of services is deprived of its use.

Cleveland is the only city with a population over 100,000 that is 100 per cent metered. The meter in general use is of the small disc type, but the velocity type is also used in certain places. A repair department maintained by the Division of Water is located at Woodland Yard, where all meters are repaired and tested. A day and night service is maintained by the Department in case of breaks or for any emergency.

The Water Department sets the hydrants for fire protection all over the city without any additional charge, and also provides the

meters and sets same without any charge. It is the only city of any size in the United States that is doing this without charging extra for the service.

It is found in comparing Cleveland's water rates with the ten largest cities in the United States, that Cleveland's rates are among the lowest.

	PER 1000 CUBIC FEET	MAXIMUM OR MINIMUM
New York	$1.00	With no minimum
Chicago	$0.62½	With no minimum
Philadelphia	$1.00	Maximum, $0.40 minimum
Detroit	$1.00	Maximum, $0.35 minimum
Cleveland	$0.60	Maximum, $6.00 per year minimum
St. Louis	$1.50	Maximum, $0.50 minimum
Boston	$1.54	Maximum, $0.88 minimum
Baltimore	$0.65	Maximum,
Pittsburgh	$1.35	Maximum, $0.90 minimum
Los Angles	$1.00	Maximum, $6.00 per year minimum

DIVISION OF WATER PROVIDES SUPPLY FOR METROPOLITAN SYSTEM

The city supplies all of the suburbs with water. In connection with this, the Division of Water bears the cost of inspection at the foundries of all pipe, special castings, valves and hydrants that are used in the construction of the system and also the cost of inspection during installation. In many of the suburbs the city collects from the consumers directly, besides rendering them the service mentioned above.

All plans for installation of water pipe must be first approved by the Division of Water. Lot owners and people who are contemplating allotting their property, apply to the Division of Water for information regarding the Department's ability to furnish them water. In many instances this is done before it is taken up with the suburbs affected. In other words, the Division of Water stands the burden of the cost of investigation of the possibilities of supply to care for future growth. In many of the suburbs the city installs the service connections, meters and meter vaults, but at the cost of the consumer.

The Division of Water from its inception has endeavored to meet the demands for water of a growing city, and is still making an earnest effort to forecast the future needs of a metropolitan center, both as to quantity and quality of its water supply.

METERING OF LOS ANGELES[1]

By George Read[2]

On February 4, 1902, the municipality of Los Angeles purchased the properties of the old City Water Company. At this time the city was growing rapidly and the water supply was, if anything, diminishing due to a cycle of dry years. The average rainfall for this section of the country is about 16.5 inches, but prior to this date the rainfall was as follows: 1897–8, 7.06 inches; 1898–9, 5.5 inches; 1899–1900, 7.91 inches; 1900–1, 16.09 inches, 1901–2, 10.6 inches, making an average rainfall of 9.44 inches for these five successive seasons.

The daily per capita consumption at this time was 300 gallons, about twice as much as it should be, and something had to be done quickly to conserve the available water supply. After considerable discussion it was decided that the only practical way to conserve the water supply was by the installation of meters.

At the time the works were taken over there were 319 metered services supplying livery stables, laundries, wineries, the oil fields and a few lodging houses. These were under a meter rate because it was hard to set a proper flat rate.

As an opening wedge, meters were set on residences where the irrigated grounds exceeded two and one half times the area of the buildings. For a short time there was considerable opposition. The business section was next given attention, and here the greatest saving was made as the plumbing, in most cases, was found in deplorable condition. Next the meters were set in those districts supplied with pumped water. From then on up to the present time meters have been set as fast as funds and time would permit. There are still 2500 services to meter. In 1912, ten years after the works were purchased, a study of consumption through 41,177 metered services showed a maximum per capita daily of 147.9 gallons for July and a minimum of 92.35 gallons for March. The

[1] Read before the meeting of the California Section, October 2, 1921.

[2] Superintendent Meter and Service Department, Bureau of Water Works and Supply, Los Angeles, California.

average daily per capita for the year was 118 gallons. These results were based on five persons per service, which was very close to being correct at that date.

Los Angeles always will have a higher per capita consumption than most eastern cities on account of it being a city of lawns and shrubbery which need watering about ten months out of the year. This per capita referred to covers metered services only. There is considerable water used outside of these for street washing, parks, fires, sewer flushing, municipal building, etc., and today this combined is estimated to make an average daily per capita consumption of 130 gallons, and reaches a high peak at times of 160 gallons. Due to the increase of apartment houses the number of consumers per service today is about 5.4.

During the first five years of public ownership of the water works, the city purchased several makes of meters, and from knowledge gained during this time the first set of specifications covering water meters for the city was written in March, 1907. From then on specifications have always been written and every improvement that would be advantageous to the City in prolonging the life of the meter has been embodied in these specifications.

In March, 1908, the Department purchased two $\frac{5}{8}$ inch meters of all the different makes that could be had, and commenced a durability test. (The reason of the $\frac{5}{8}$ inch size being chosen is that about 92 per cent of the meters in service are of that size.) These meters were thoroughly tested before placing for the test, on two flows, one at the rate of two cubic feet per minute, and one at the rate of ten cubic feet per hour. They were then run steadily, night and day, at the rate of one cubic foot per minute, one half their rated capacity. This rate was chosen so that no manufacturer could claim that the meters were being run beyond their rated capacity.

When the meters reached a registration of 25,000 cubic feet, they were taken off the line and again tested on the two flows, two cubic feet per minute and ten cubic feet per hour. The next test was made at 50,000 cubic feet recorded, the next at 75,000, and so on until the meter reached a registration of one million cubic feet. The meter was then taken off the line, overhauled and made practically as good as when new. All the parts, etc., that were necessary to make the meter practically as good as when new plus the parts, etc., that were needed to keep the meter running to reach a registration of one million cubic feet, were charged up to the meter.

It took about two and one-half years to complete this test, and by means of it several weak spots were overcome. A meter under this kind of a test does not show the effects of corrosion as it would have if it had been in actual service, because water passing through the meter continuously tends to retard corrosion. Also the wear throughout the meter is not as great as if it had been in actual service, because the meter is running continuously at a steady pace and not subjected to hydraulic shocks through turning off and on all the time.

All the makes of meters were working, however, under the same conditions, and the showings made were quite different in some cases. We consider that the knowledge gained paid well for the time and trouble and today we are still testing the same way.

TYPES OF METERS USED FOR DIFFERENT KINDS OF SERVICE

Disk piston meters are used from $\frac{5}{8}$ inch to 2-inch inclusive. For large office buildings, etc., requiring 3- and 4-inch meters, where the consumption as a rule is steady and where sensibility is the important factor, an oscillating piston type of meter is used. So far this type of meter has given the City the best service for this kind of use. It is expensive but dependable. Large services for fire protection, supplying only sprinkling systems, are not metered.

We consider it an imposition upon the consumer to install at his expense a large costly meter which might do harm and certainly do no good as far as the consumer is concerned. We insist on the piping from fire services being entirely separate from the domestic supply and we endeavor to inspect these services yearly, by shutting off the domestic supply and going through the premises. If we find water anywhere, it must be coming from the fire service. To date we have found only one case where this was really abused, and in that case the department imposed a pretty stiff penalty.

Services supplying sewer flush tanks are being metered with Jet meters as fast as time and funds will permit. We have 4600 of these connections, including San Pedro, and at this date 2723 are Jet metered.

The water is discharged into the tank through a hard vulcanized rubber disk and is calibrated to discharge as nearly as possible 300 gallons in twenty-four hours. It is practically impossible to make the calibration perfect for this amount in a given time, due to pressure variation.

There are several good water meters on the market today and, in fact, all meters are better than they were a few years ago. Nevertheless the Department finds it good policy to standardize on as few makes as possible. The meter repairmen become more efficient, repair parts can be more intelligently ordered in advance, changeability of meters in service is assured, and the meter shop can be properly equipped for repairing.

METHOD OF METER SETTING

As we are not bothered with freezing, our meters as a rule are set just inside the curb. They are placed on a riser from the service so that the face of the register is about 3 inches from the surface. This makes the reading of the meters and the changing of inactive meters, etc., easy and quick, and it also allows the use of an inexpensive shallow meter box.

We have a local building ordinance which prohibits basements under sidewalks extending further than 3 feet from the curb. This strip was reserved by the City for the installation of fire plugs, meters, electrical conduits, and other public utility equipment.

We have a few meters in basements where the basement extends to the curb. These basements were made prior to this ordinance. The few that we have are a nuisance. The meter-readers must get permission to enter, hunt keys and carry flash lights. Stuffing boxes are likely to leak and to cause damage. There is also a likelihood of a meter bursting and causing a great deal of damage.

When a large service must be metered in a basement we prefer a battery of 2-inch all bronze meters with valves governing the inlet and outlet of each meter. We consider a 2-inch all bronze meter not near as likely to burst as a 3 or 4-inch meter with main casing made of cast iron. In addition, if one meter stops operating it can be changed without shutting off the entire supply. Batteries have advantages and also disadvantages.

On services supplying large industrial plants, where at times it would be inconvenient and costly to the consumer to have the water cut off while changing the meter for repairs, we place a valve on each side of the meter and run a bypass pipe equipped with a valve around the two valves governing the meter. The bypass valve is left closed and sealed and when it is necessary to change the meter for repairs, etc., we open this bypass valve and then close the two valves governing the meter, thereby not interrupting the service.

METER COVERS

For covering meters in parkings, lawn or no lawn, a cement meter box 9 inches square by 11½ inches deep, is used—what we call our no. 1 meter box.

This box does not cover the curb cock and in fact we try to discourage the using of curb cocks by the consumer and recommend that they have a wheel valve placed by a plumber to control their water supply in case of needed repairs to leaky fixtures. The reason we try to discourage the consumer from using the curb cock is that in many cases they ruin them and frequently leave a hole dug out in front of the meter box which is a menace to the public.

We have specifications covering our curb cocks from ½ to 2-inch and they are standard all over the system. If any curb cock has to be renewed the space for the setting of the meter is retained. We also have a standard (fool proof) locking device for our curb cocks. By fool proof we mean that no curb cock can be clamped and sealed unless it is closed. Just before the world war broke out we were intending to cover meters in well kept lawns with a concrete meter box large enough to cover meter and curb cock both, and we still intend to do this when times get back to normal.

For housing meters set in cement walks we use a concrete well and a cast iron plate, large enough to house the meter and the shut off. A wooden form made from 1 x 12 R. O. P. rabbited ¾ x ¾ is set in position and concrete poured around it. The plate then rests on the wooden form while the concrete is setting. Three sizes of plates are generally used as follows:

For covering ⅝ to 1-inch meters, the plate is 23½ x 15¾ inches, weighs 60 pounds and costs at this date $3.00 each. For covering 1½- and 2-inch meters, the plate is 30 x 22 inches, weighs 121 pounds and costs $6.00 each. For covering 3- and 4-inch meters, the plate is 46 x 26 inches, weighs 180 lbs. and costs $9.00 each. We also have a large plate, 64 x 26 inches, which we use at times to cover a fire-service gate and domestic meter.

When a sidewalk is being extended to the curb, taking in small concrete meter boxes that do not cover the curb cock, the Department requests the contractor to leave the top of the boxes level with the surface of the new walk and cement around them. Later on when the walk is thoroughly set, and it is convenient to the Department, a meter plate according to the size of the meter is laid on the sidewalk square with the curb, so that the meter register

comes in the center of the plate. A hole in the sidewalk is then cut about a quarter of an inch larger than the plate, taking care not to crack the walk outside of the mark. The hole is excavated to about 3 inches below the bottom of the meter and the sides and ends of the hole extended about 2 inches under the walk. After the bottom of the hole is tamped, a wooden form is set covering the meter and the cut off. The plate is then set on the form and tamped down until the top of the same is level with the sidewalk. The plate is then removed and concrete is grouted all around the form to the surface. The plate is then put back and rests on the form while the concrete is setting. In time this wooden form rots away and leaves the plate resting on the concrete. A hole is left in the ends of boxes in case piping to meter has to be renewed.

This method of setting meter boxes and plates eliminates the cost of resurfacing, matching colors, covering while setting and gathering covers.

METER TESTING

Meters are tested before they leave the factory, but to make sure they are correct the City again tests all meters before they are set. Our shop is equipped with three round galvanized iron tanks 22 inches in diameter by 4 feet 11 inches high for testing meters from $\frac{5}{8}$ to 2-inch. Each tank is equipped on the outside with a $\frac{3}{4}$-inch O. D. glass tube, running the entire height of the tank. These glass tubes are equipped with buret floats on account of capillary attraction of water and graduated in three stations, viz., beginning point, 5 cubic feet, and 10 cubic feet, which is stopping point. These buret floats have projections to keep them from adhering to the glass tube, and contain enough quick-silver to about half submerge them. The inlet is at the bottom of the tank and the piping is so arranged that the head of water is killed when entering the tank, allowing it to rise steadily in the glass tube, so when whipped off at any flow it remains still. The 5- and 10-feet stations are determined by weighing the water into the tank at $62\frac{1}{2}$ pounds per cubic foot, so when a meter is tested the water is practically weighed through the tank readings.

These tanks were made tall and small in diameter to insure a big displacement for a small amount of water. Each tank is used to test four to five meters at a time by connecting them together with meter couplings. These meter couplings are joined together with a

tee equipped with a lever handle valve for running each meter up to an even figure.

The register boxes of all meters are sealed after testing and no meter is taken from the meter shop for setting unless it is sealed.

We also have a large reinforced concrete tank 13 feet 10 inches square on the outside. This tank is divided into three sections. One section contains 900 cubic feet, one, 100 cubic feet, and one, 10 cubic feet. It is also equipped with a glass tube and buret float and is used for the testing of larger meters, etc.

During the last fiscal year the Department tested an average of 2000 meters per month.

Our testing tanks are kept clean and are satisfactory in every respect.

METER REGISTRATION

A great many people really believe that water meters rob them by over-registering, and request that their meter be tested. We explain and try to talk them out of having it done, but sometimes the more we explain the more determined they are to have the test made. We then take their order and request that they or someone witness the test and tell them that if we find the meter over-registering, that there will be no charge for the test, and that we will rebate the back bills already paid. The charge for testing is as follows: $\frac{5}{8}$ to 1-inch, \$1.50; $1\frac{1}{2}$- to 2-inch, \$2.50; 3- and 4-inch, \$5.00; 6- and 8-inch, \$6.00.

The $\frac{5}{8}$- and 1-inch as a rule are tested at the premises, by shutting off the water, taking the meter out and connecting it to the curb cock with a piece of hose. Then a meter of known registration on variable flows equipped with a valve on the outlet side is connected to the meter to be tested. Larger sizes are taken to the shop to be tested, leaving a new meter in its place, and if the meter being tested is low in registration or needs any repairing it is not put back. In twenty years of experience I cannot recall over two cases where meters were found over-registering enough to warrant any rebate and those were very small.

We have yet to test a new meter that will describe an absolute straight line on variable flows. There is always a flow which shows a high peak of registration; because at this particular flow the meter is more positive in displacement than at any other; it does not show show a loss through sensibility or a slippage by over-running. At

high peak registration flows we aim to test and gear our meters and they usually leave the shop recording 98 to 101 per cent.

When a disk piston meter is new, one complete nutation or gyration of the disk means the passage of a quantity of water equal to the effective volume of the chamber. Any slight slippage due to the piston not perfectly fitting the chamber is taken care of by the change gears.

After this meter has been in service for a few months and the draft has not been high and the water has been free from grit, etc., there appears a deposit of slick vegetable matter on the piston, and all over the inside of the measuring chamber. This deposit tends to lessen slippage and slightly reduce the quantity of water displaced by each nutation of the disk, hence the meter shows a slight increase of registration.

This kind of a deposit acts as a lubricant and tends to prolong the life of the meter. The increased registration through the meter is negligible and, as a rule, short lived, and the consumer has nothing to fear in this respect. On every meter that was taken out for not operating, due to being worn out, it is safe to say that the consumer got more water than he paid for.

The Department has some meters in service equipped with straight reading intermittent registers that require close watching. Most of these meters were acquired through the taking over of water companies by the City. This type of register can over-register at times, by one of the mutilated gears creeping back on its shaft and getting on the face of the counter wheel which drives it. This gear then becomes disengaged from the next higher counter-wheel which it should drive and leaves it free. The first counter wheel is fastened on the shaft that the other wheels revolve upon and as this shaft revolves the disengaged counter wheel at times creeps with it.

This intermittent straight reading register is gradually being replaced with the round dial constant moving type. This faulty construction, well known to us, is closely watched and before long will be a trouble of the past. If the consumer knew how careful the department is in regard to the testing of meters before they are set and what a remote chance there is for his meter to over-register I think he would be perfectly satisfied. Of course, there is always a chance of the meter being over-read by the meter-reader and most of these are caught before billing.

METER REPAIRING

Practically all meter repairing is done at the meter shop. The only work done in the shape of repairs to meters in the field is the renewing of registers that have been broken. Main casings of our velocity meters are left on the service. The cover containing gear train and register is removed and the cage containing propeller is taken out. These parts are then replaced with new ones and the old parts are brought to the shop for repairs. This eliminates a lot of hard and costly work. Our facilities for repairing and testing meters are very good. The shop contains concrete benches for testing, repairing and storing the meters ready for setting. The machinery consists of a lathe, pipe threading machine, wire wheels for cleaning the outside of meters and exhauster for carrying away the dust, grind stone and carborundum wheels, circular saw for cutting lumber for meter box forms, ball socket machining machine, gages, press diaphragm cutter, etc. The machinery is run by six induction motors. Our force consists of a superintendent who passes on meter parts, whether they are to be repaired or wholly replaced, and sees that every meter is properly repaired (not tinkered with). He also takes care of all repairs to service equipment.

Under him are two testers, a machinist (considered a meter repairer) and five meter repairers. A chief clerk and assistant make permits for street excavations, check meter and service work done against daily time cards, make monthly inventory of meters in stock for Los Angeles, San Pedro and San Fernando Valley, post maintenance cards, order, receive and record meter and service supplies, make monthly reports of all meters set and check these with office records, and are responsible for all meters leaving the shop. On September 1, there were 126,052 meters in service, which at this date means one meter repairer for each 21,000 meters in service. The Department takes out monthly about one meter for every two hundred in service for not operating, due to all causes.

In the last twelve months 161 meters were taken out monthly for failure to operate, due to hot water or steam backing up from boilers or heaters. On the first occurrence of a meter being damaged by hot water or steam supplying a residence, a post card is mailed the consumer, notifying him and requesting that care be taken to guard against a similar occurrence. On the second occurrence, a bill is rendered the consumer covering the cost of changing and repairing

the meter. When meters are likewise damaged, supplying places of business, a bill is rendered on the first offence. The Department advises consumers to watch their heaters and not to use a check valve on their service, as it is cheaper to pay for repairing meter than to run the risk of bursting a boiler.

The organization of the Meter and Service Department consists of a general superintendent with four assistants. One has charge of the field meter and service operation and office meter and service records. The second has charge of meter and service installation and service maintenance. The third has charge of all meter repairing and upkeep of service equipment and the fourth receives, records and distributes service orders and is a general assistant.

The total force of the meter and service department at this date consists of 105 men, and they cover Los Angeles, San Pedro, San Fernando Valley and the West Gate District.

The city of Los Angeles was incorporated on April 4, 1850, and at that date its total area was 28 square miles. Today it covers an area of 366 square miles, a square mile for every day in the year.

The new domestic service installations for the last twelve months, covering all districts, have been at the rate of 1025 per month, and today show no signs of falling off.

On September 1, 1921, we had 136,970 services of all kinds and 123,052 meters. We have also a little over 3000 irrigation services and meters in the San Fernando Valley, which makes a total of 126,052 meters to maintain.

A LONG RECORD OF MICROSCOPICAL EXAMINATIONS

By George C. Whipple[1]

The spectacular publicity given by the daily press to the recent occurrence of Synura in the water supply of New York City has tended to renew a somewhat flagging interest in the general subject of microscopic organisms in water. It may be worth while, therefore, to call attention to the long record of microscopical examinations of the water supply of Boston which were begun by the writer in 1889 and which are being continued without change of method in the laboratory of the Metropolitan District Commission. Some day these data, together with those begun a few years later in the Mount Prospect Laboratory of Brooklyn and perhaps others, ought to be assembled and studied critically in order to search out correlations between the growths of the organisms and certain climatic, physical and chemical factors which may help to explain the reasons for their erratic occurrence. As examples of these long records a few diagrams are here presented.

Figure 1 shows the microscopic organisms in Wachusett Reservoir from 1898 to 1920. The data represent weekly tests of surface samples. They are plotted by months, the median for each month, as well as the maximum and minimum, being shown. It will be remembered that the top soil was removed from the site of this reservoir. Although the storage of water began in 1898, the reservoir did not fill until 1905, since which date there has never been any great depletion. During the filling period, there were few organisms in the Wachusett water. Its color at this time was quite high, and the conditions of light were not favorable to the development of plant life. Since 1905, there have been fairly regular growths of algae, and at times some rather heavy growths. Asterionella has been the most troublesome, but other diatoms and even the blue-green algae have been present in numbers sufficient to cause

[1] Professor of Sanitary Engineering, Harvard University, Cambridge, Massachusetts; also Hazen, Whipple and Fuller, New York.

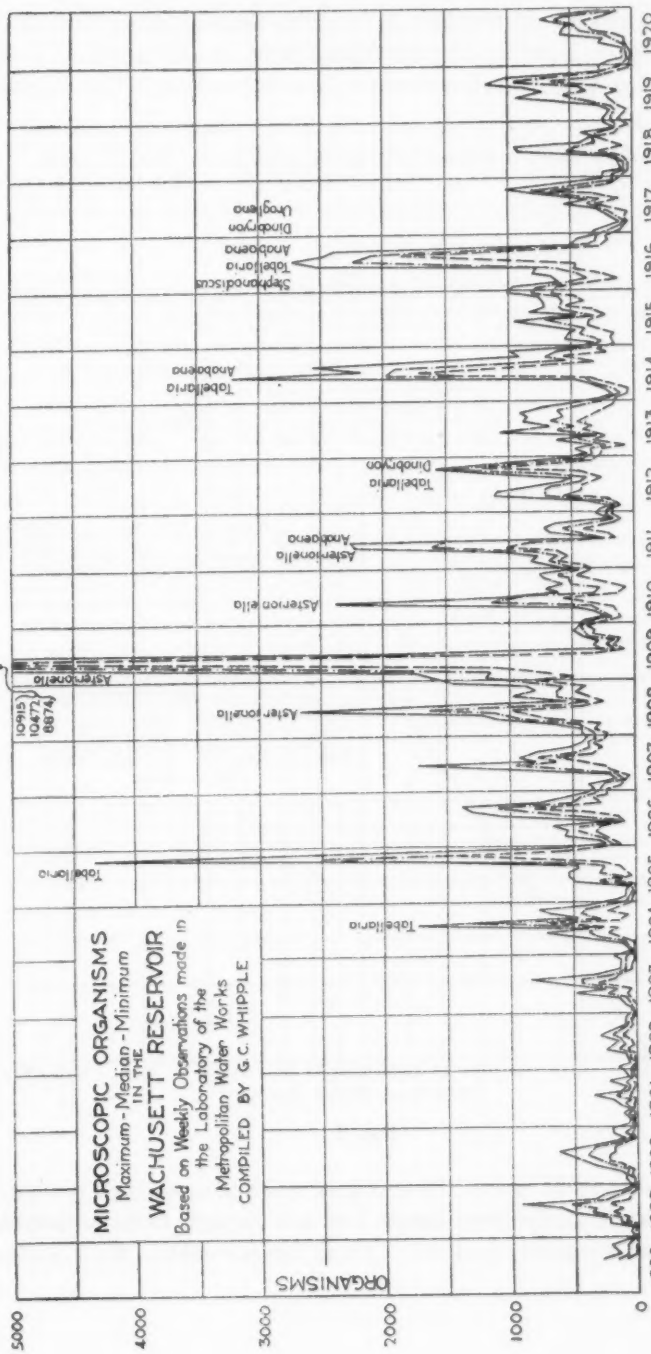

MICROSCOPIC ORGANISMS
Maximum - Median - Minimum
IN THE
WACHUSETT RESERVOIR
Based on Weekly Observations made in the Laboratory of the Metropolitan Water Works
COMPILED BY G.C. WHIPPLE
ORGANISMS
5000
4000
3000
2000
1000
0
1898 1899 1900 1901 1902 1903 1904 1905 1906 1907 1908 1909 1910 1911 1912 1913 1914 1915 1916 1917 1918 1919 1920
Tabellaria
Asterionella
Synedra
Dinobryon
Uroglena
Stephanodiscus
Anabaena
10915
10472
8874

Fig. 1

noticeable odors. If the data for the ten recent years (1909–1919) are plotted on logarithmic probability paper, as in figure 2, it will be seen that they fall on a straight line or nearly so. The median

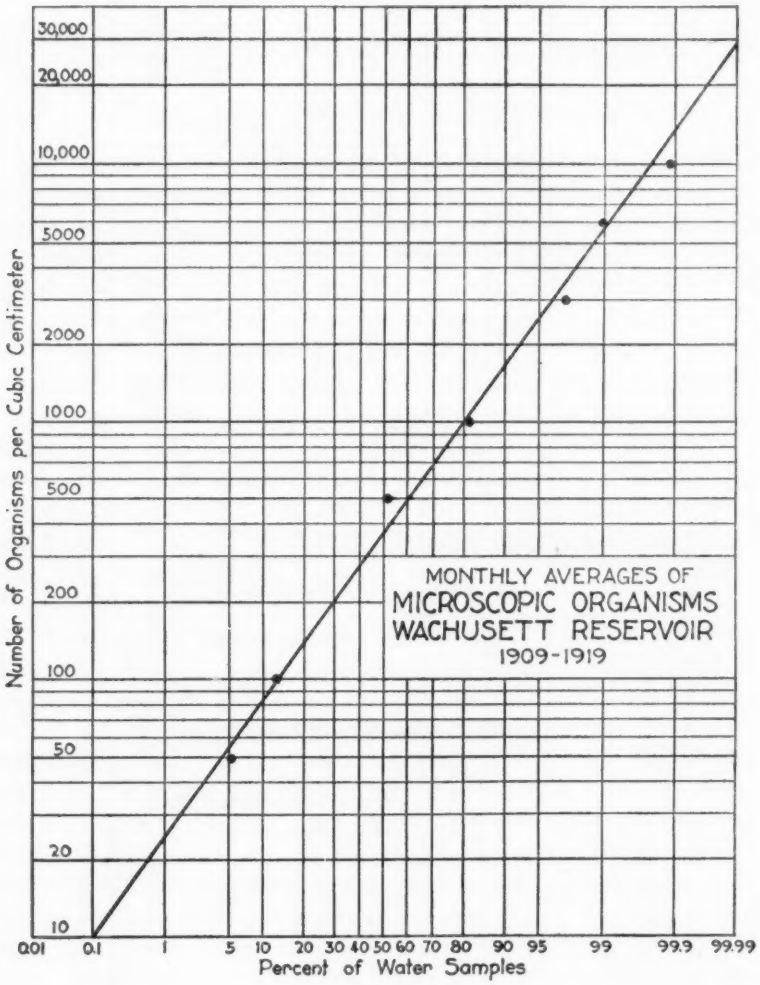


FIG. 2

figure is seen to be about 350 standard units of organisms per cubic centimeter—a fairly large figure but not enough to be noticeable, considering the genera present. About ten per cent of the examina-

tions showed more than 1500 and one per cent of them showed more than 5000 units per cubic centimeter. It is evident that the soil stripping of the reservoir site did not entirely prevent the growth of algae.

Figure 3 shows the microscopic organisms in the Sudbury Reservoir, through which the Wachusett water passes on its way to the city. Some of the high points on the curve are due to growths which began in the Wachusett Reservoir, but the Sudbury Reservoir also has its own seasonally recurring organisms.

Figure 4 shows the results of microscopical examination of Lake Cochituate water from 1892 to 1920. This is a natural lake. It was used regularly from 1848 to about 1909, since which year it has been held as a reserve supply drawn upon infrequently. Lake Cochituate has always been famous for its algae growths, but since it became a reserve supply the growths have been heavier than before, and whenever the lake has been drawn upon the characteristic odors of the organisms usually cause complaint in the city.

Ultimately these water supplies will have to be filtered.

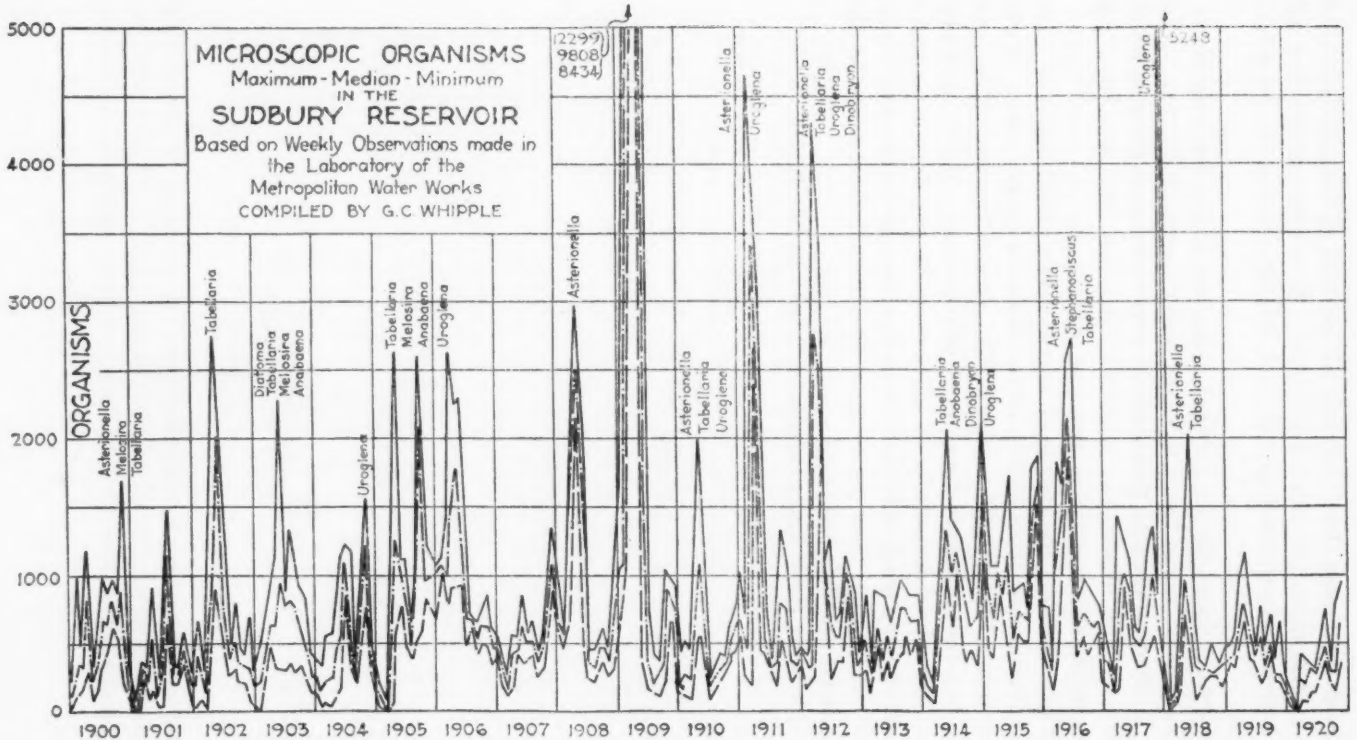

MICROSCOPIC ORGANISMS
Maximum - Median - Minimum
IN THE
SUDBURY RESERVOIR
Based on Weekly Observations made in the Laboratory of the Metropolitan Water Works
COMPILED BY G.C WHIPPLE
ORGANISMS
5000
4000
3000
2000
1000
0
1900 1901 1902 1903 1904 1905 1906 1907 1908 1909 1910 1911 1912 1913 1914 1915 1916 1917 1918 1919 1920
Asterionella Melosira Tabellaria
Tabellaria
Diatoma Tabellaria Melosira Anabaena
Uroglena
Tabellaria Melosira Anabaena Uroglena
Asterionella
(22999) 9808 8434)
Asterionella Tabellaria Uroglena
Asterionella Uroglena
Asterionella Tabellaria Uroglena Dinobryon
Tabellaria Anabaena Dinobryon Uroglena
Asterionella Stephanodiscus Tabellaria
Uroglena
(5248)
Asterionella Tabellaria

FIG. 3

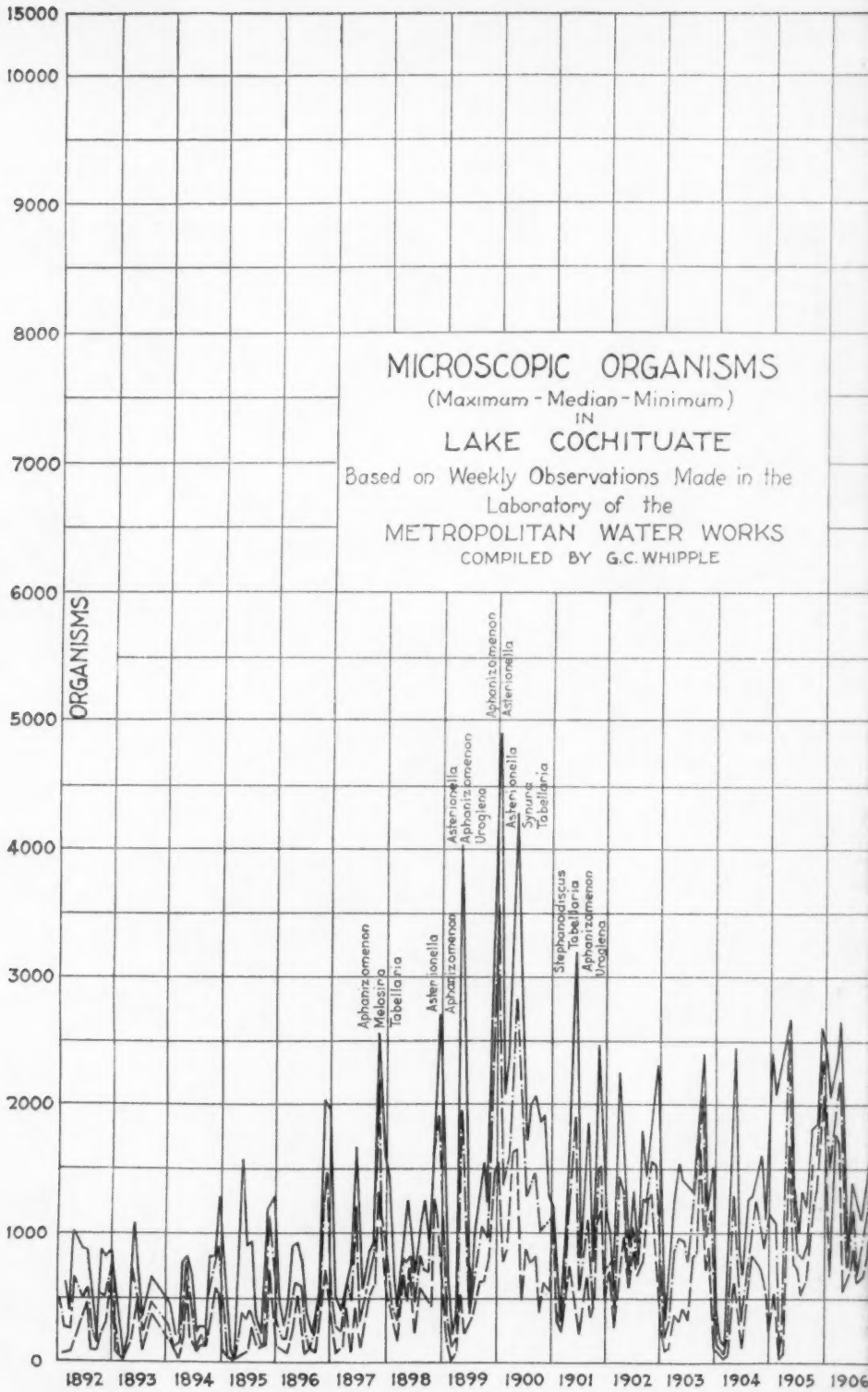

MICROSCOPIC ORGANISMS
(Maximum - Median - Minimum)
IN
LAKE COCHITUATE
Based on Weekly Observations Made in the Laboratory of the
METROPOLITAN WATER WORKS
COMPILED BY G.C. WHIPPLE
ORGANISMS
15000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
Aphanizomenon
Melosira
Tabellaria
Asterionella
Aphanizomenon
Asterionella
Aphanizomenon
Uroglena
Aphanizomenon
Asterionella
Asterionella
Synura
Tabellaria
Stephanodiscus
Tabellaria
Aphanizomenon
Uroglena

FIG. 4

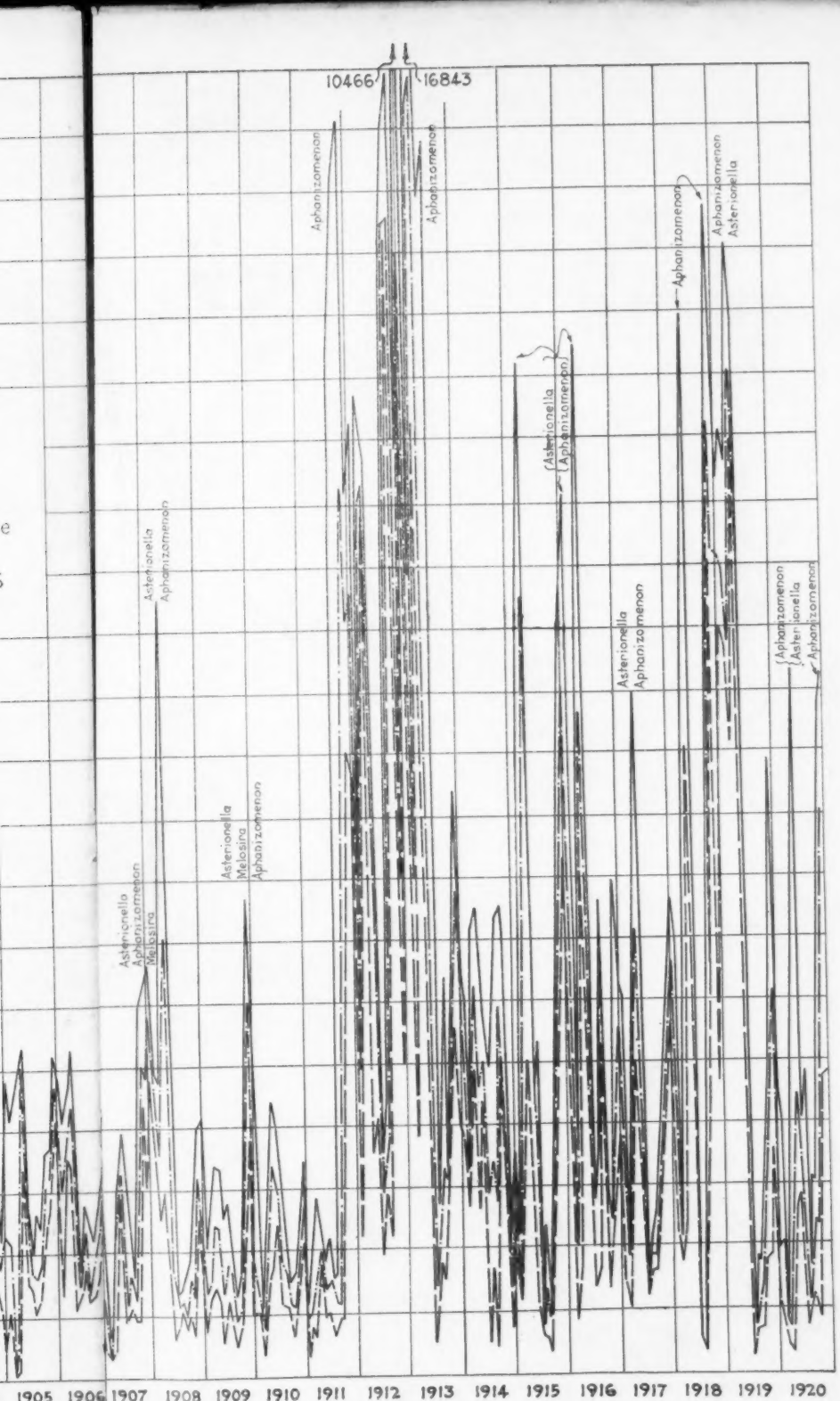

10466
16843
Aphanizomenon
Aphanizomenon
Aphanizomenon
Asterionella
Aphanizomenon
Asterionella
Melosira
Aphanizomenon
Asterionella
Melosira
Aphanizomenon
(Asterionella
(Aphanizomenon)
Asterionella
Aphanizomenon
Aphanizomenon
Aphanizomenon
Asterionella
(Aphanizomenon
(Asterionella
Aphanizomenon
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920

FIG. 4

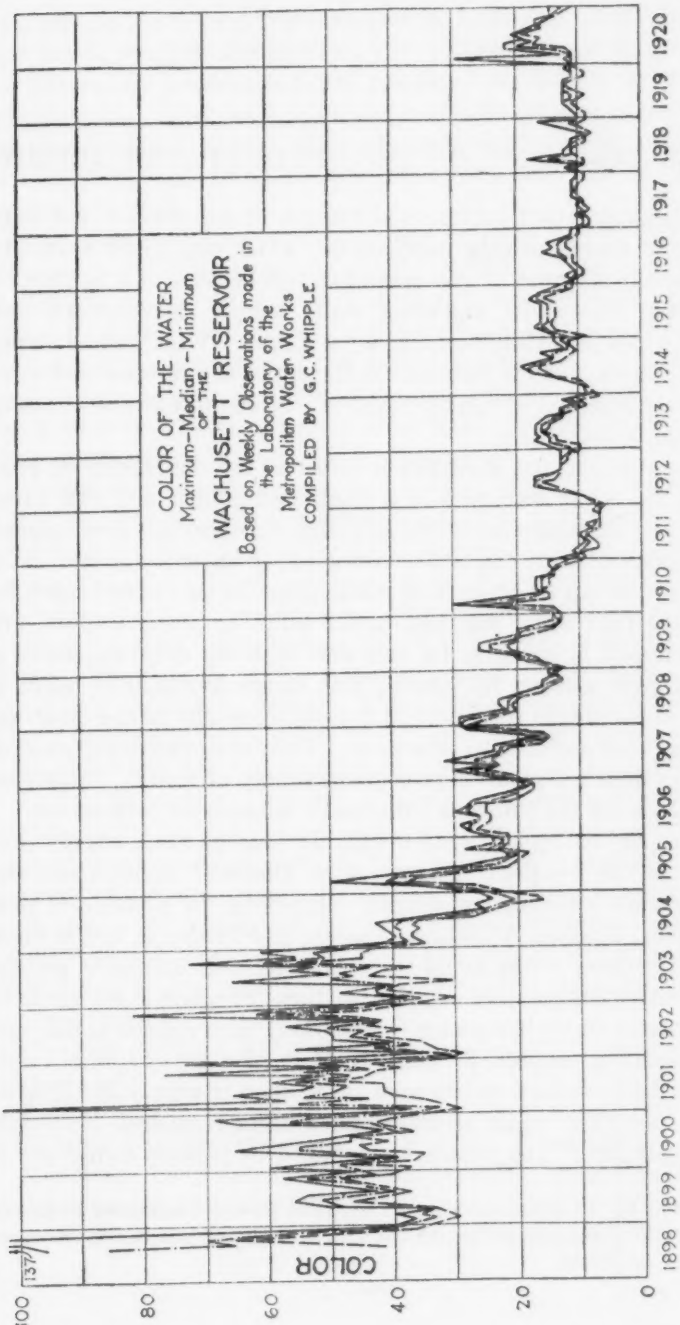

COLOR OF THE WATER
Maximum–Median–Minimum
OF THE
WACHUSETT RESERVOIR
Based on Weekly Observations made in the Laboratory of the Metropolitan Water Works
COMPILED BY G.C. WHIPPLE
COLOR
137
100
80
60
40
20
0
1898 1899 1900 1901 1902 1903 1904 1905 1906 1907 1908 1909 1910 1911 1912 1913 1914 1915 1916 1917 1918 1919 1920

Fig. 5

WATER RESOURCES OF THE STATE OF NEW JERSEY[1]

The present report is of special interest to our readers, not only because of its engineering implications, which one might naturally anticipate in a report of this character, but because of a number of interesting viewpoints regarding water supply development and control which Mr. Hazen tentatively suggests. Whether one agrees or not with some of his recommendations, yet the interest and novelty of the suggestions remain sufficiently strong to warrant directing attention to them here.

It is not often that attention is called to the desirability of conserving the water resources of a single community and still rarer is it to find an injunction which seriously considers the development and conservation of the water suppplies of an entire state. The author points out an interesting justification for this latter principle, by noting that water supplies, unlike other natural resources, are not decreased in capacity by use; and that the development of a water supply assures its present and future availability, while a failure to undertake conservation frequently results in the diversion of water rights and sites to other uses. The mere existence of natural resources does not insure a permanent supply of water. Conscious preparation for the future is a necessary adjunct for permanency.

The report outlines in some detail, the present water supply conditions in the so-called "Metropolitan District" (with which the investigation is mainly concerned), comprising the counties of Bergen, Essex, Hudson, Middlesex, Passaic and Union, in which there are thirty-three water supply systems, serving 2,070,000 people. Quantitative information relative to these supplies is set forth in tabular form in the discussion. Important facts appear in this survey of existing supplies, of which the following are of special interest. In 1920, surface waters were called upon to supply 204,000,000 gallons per day, while underground sources furnished 40,000,000 gallons per day. The population supplied by publicly owned plants

[1] Review by the Editor of a report by Allen Hazen, Consulting Engineer, of Hazen, Whipple and Fuller, to the Board of Conservation and Development of New Jersey.

was 983,335, that by private companies, 1,087,147. The effect upon per capita consumption in these two classes appears in the figures of 139 and 99 gallons per capita per day, respectively, for the above populations. Likewise, in 12 systems with 90 per cent or more of the services metered, the per capita consumption was only 89, while it averaged 154 gallons in 21 systems having less than 90 per cent metered services.

The author estimates the capacities in a dry year of the present sources as 268,000,000 gallons per day. With a daily consumption in 1920 of 244,000,000 gallons, it is clear that action looking toward the extension of existing and the incorporation of new water sources is important. Considering the future requirements of both public and private industrial water users, Mr. Hazen concludes that the total water requirements will be 575,000,000 and 880,000,000 gallons daily in the years 1950 and 1970, respectively.

Fortunately abundant sources of water supply are available in the State. In addition, the population needing water is concentrated within short distances of favorable sources. Within 50 miles of urban centers are found catchment areas of 1718 square miles, that might be made tributary to future water works. Of this, 1577 square miles are in New Jersey and amount to 21 per cent of the area of the State. The streams in the southern part of the State are not included in the above figures. The complete development of the above catchment areas would yield 1,550,000,000 gallons per day, only a little less than twice the amount estimated as required in 1970.

In this connection, also, Mr. Hazen advises much more comprehensive and deliberate action than is usual in such matters, by suggesting the possible purchase of certain areas of watersheds for the purpose of removing from the market as much as possible of the land and to make long term leases to present owners. It would be fruitful to gain some discussion on the wisdom or possibility of such a policy of permanent artificial control of the parts or whole of watersheds.

The four principal developments considered for the Metropolitan District are:

1. Complete or partial development of the Passaic River.
2. Long Hill Reservoir fed by northern streams.
3. Raritan development, supplemented ultimately if needed, by water from the Delaware River.
4. Mullica and Wading Rivers, and other southern streams.

It is estimated that the probable capacities and costs of these four projects are as follows:

	PASSAIC GREAT RESERVOIR	LONG HILL SYSTEM	RARITAN	MULLICA AND WADING RIVERS
Total cost, millions of dollars.....	101	130	110	125
Capacity, million gallons per day	450*	750	400	300
Cost per million gallons daily capacity, dollars.....	225,000	173,000	275,000	417,000

* In addition to 200,000,000 gallons now obtained and allowing for a flow of 80 million gallons daily for lower river water rights.

The author points out that the Long Hill system is in general more advantageous than the Passaic Great Reservoir, on account of greater elevation of water in the former, absence of pumping, smaller population on catchment area, and the possibility of progressive development, whereas the Passaic scheme would require immediate and almost complete initial construction. This latter scheme, however, offers advantages in flood protection of the lower Passaic valley which do not appear in the Long Hill system. The Mullica and Wading Rivers are considered to be too far distant for economical development, while the Raritan, although furnishing an excellent supply at a reasonable cost, is more expensive than the other available resources.

It is definitely recognized in the present report that a comprehensive solution of a problem which involves such a diversity of ownership as is represented by thirty-three separate systems is not to be expected through voluntary cooperation. For this reason, the creation of a state water board is recommended. This board is to be given the power to acquire existing sources of supply, lands and rights for additional sources, to build water supply works, to sell water at wholesale and to issue bonds to pay for its undertakings. The board is to be composed of three members. The manner of selecting these is, however, not suggested, although it would have been helpful if the author had established a definite procedure, such as appointment by the governor or joint selection by governor, state board of health and public service commission (or its equivalent). Sometimes such specific recommendations do much to eliminate subsequent political controversies.

The board as here constituted is to furnish water at wholesale to any municipality or water company in the six counties. With such an arrangement, the board will control only the main distributors and but little of the local distribution systems. In the same manner, it may exert no authoritative supervision over the consumption of water. Although this plan provides for a maximum degree of local autonomy, it might be questioned whether greater economy in engineering and financing might not result by complete control of the enterprise, in all of its ramifications, by the governing board. The subsidiary portions of a water system are so closely linked, in plan and in control, with the main supply that it is difficult to see why their management should be separated.

Another interesting suggestion upon which some might take issue with Mr. Hazen is the reference to the possibility of a dual system of water supply for the territory here discussed. After showing that industrial uses are quite as great as domestic uses, the author pertinently inquires "why not have two grades of water like two grades of milk? Grade A water to be used for the primary system and for all domestic purposes, and Grade B water to be used for industrial purposes?" As Mr. Hazen recognizes in his further discussion of this problem, the final answer rests, on the one hand, upon a comparison of charges for auxiliary distributors for industrial use as against additional pure water supply and, on the other, upon the public health danger of even a heavily chlorinated industrial water supply (as the report suggests). Where additional pure water, because of industrial demand, is even slightly more costly than an auxiliary impure supply and its necessary appurtenances, prudence might warrant the greater expenditures.

THE CEMENT GUN IN WATER WORKS PRACTICE[1]

By L. R. Talbot[2]

In the past eight or ten years the cement gun has become closely identified with the water works business. During that period a large number of reservoirs have been built or repaired by the use of the cement gun. There is hardly a state in the country which has not within it an example of the successful application of this method. The territory represented by the members of this Section can offer a large number of such illustrations, while Muscatine, Iowa, holds the distinction of being the first city to have had a reservoir lined in this manner.

For this reason, it is a pleasure to describe to you briefly the elements of this process and to point out a few of the many instances of its application.

"Gunite" is the cement and sand product of the cement gun. This material has been successful in this kind of work because, when properly placed, it makes a water-tight job, which will not crack or check when properly reinforced. As it is placed with an air pressure of from 30 to 40 pounds per square inch, it is driven into the surface and forms a coating that is 40 per cent more dense than hand or machine mixed mortar. In other words, the same amount of dry material when deposited by the gun would require only 60 per cent as much volume as the same amount placed by hand. Because of this density, its strength is over twice that of ordinary concrete.

The material may be placed at a considerable distance from the gun, thus obviating the necessity of an extensive handling plant. A thin coating may be applied without the use of forms or other preparatory work, except cleaning the surface and applying the reinforcing, both of which must be done in any case.

The gun is adaptable for building new reservoirs which are above ground, as well as lining the excavated type. Seven years ago, a

[1]Presented before the Iowa Section, November 2, 1921.

[2]District Manager, The Cement Gun Company, Inc., Allentown, Pennsylvania.

reservoir was built at Elmhurst, New York, without the use of forms of any kind. The reinforcing was erected and a light frame used as a backing until enough material had been deposited to support itself, when the frame was moved ahead. A better scheme than this was used at Ford-City, Pennsylvania, last year, where a circular reservoir 110 feet in diameter and 17 feet deep was constructed of "Gunite." The only poured work was that for an annular footing slab under the wall. Vertical reinforcing consisted of one inch square rods and horizontal reinforcing was one inch twisted bars, spaced according to pressure requirements. Two layers of mesh reinforcings were used. The reinforcing was erected entirely and tied together, then a light wood form or backing was built on the outside and against the steel. Mesh was applied to the inside and the inside was "shot." The forms were then removed and another layer of mesh applied to the outside and the outside was shot, bringing the wall to the required thickness. The walls were 13 inches thick at the bottom and tapered to 5 inches at the top. The floor was about 4 inches thick and reinforced with mesh in both directions. It has been in use about a year now and is giving perfect satisfaction. The contract price was $45,000 complete, which was less than bids that were received by the city for a poured concrete tank of the same dimensions. Labor and material prices when the job was built were about at their peak, so that a similar tank could probably be built at the present time for much less money.

At Kansas City, the Turkey Creek reservoir was lined last year and put in good shape and beyond the need of repairs for a long time to come. At the present time they are finishing up a portion of the Quindaro reservoir at the same place.

Trouble in maintaining linings, at Council Bluffs due to ice conditions and general deterioration, was experienced. The walls were cleaned off and a coating of reinforced "Gunite" was applied to solve the difficulty. In addition, the new reservoir is having a light coat applied over the surface for water proofing purposes.

The reservoir at Mt. Vernon, Iowa, showed ground water seepage. The reservoir is underground, the bottom being 26 feet below the surface. The seepage amounted to about 100,000 gallons in twenty-four hours when the reservoir was kept pumped down. When it was decided to remedy this condition, the reservoir was pumped down and about 20 weep pipes were put in to take care of the inflow, thus drying the walls. "Gunite" was applied in successive coast,

until 5 inches had been placed over the area where the seepage was worst. Finally the pipes were capped and were covered with a knob of "Gunite." No trouble has since been experienced.

One of the largest jobs done this year, amounting to about 250,000 square feet, was the lining of the walls of the reservoir at Nashville, Tennessee Some work was done at Nashville in 1914 which was successful. The present job consists of coating the entire surface walls with "Gunite," then placing a coating of mastic, and finally a 3-inch coat of "Gunite."

At Pittsburg, Pennsylvania, a few years ago, the Herron Hill reservoir, which is of 10,000,000 gallons capacity and the oldest in the city, was leaking at the rate of 1,000,000 gallons a day or 10 per cent. It was cleaned out, and a 2 inch "Gunite" lining was applied, reinforced in both directions with American Steel and Wire triangular mesh. It was estimated that a saving of $70,000 was effected on this job by using "Gunite" rather than a poured double slab, which was what they had originally intended to use. The lining was made continous with no expansion joints. A solid panel fence was built around the reservoir and a watch house was built with the cement-gun. A test made after the completion of the work showed a loss of less than 10,000 gallons in twenty-four hours, with no correction for evaporation.

Much the same methods were used in lining the Lake Elizabeth reservoir on the North side of Pittsburgh, and this fall it was decided to line the Highland reservoir No. 2. This is a 100,000,000 gallon reservoir and totals 750,000 square feet, of which about 75,000 square feet are being surfaced this fall and the remainder is to be done next season.

In addition to the projects enumerated above, brief mention should be made of similar work carried out at Montreal, Quebec, on the Outremont Reservoir, at San Francisco, California, on the Twin Peaks Reservoir, at Elmira, New York, and at Great Falls, Montana for the Anaconda Copper Company.

REPORT OF THE AMERICAN COMMITTEE ON ELECTROLYSIS, 1921

A Review by Victor B. Phillips[1]

HISTORY OF THE COMMITTEE

The American Committee on Electrolysis was organized early in 1913, upon the initiative of the American Institute of Electrical Engineers. The purpose of the Committee was to study the subject of electrolysis "comprehensively, and endeavor, if possible, by co-operation" by the several national societies interested and "with other interested associations and corporations to gather and classify information, and if then found feasible to agree upon and recommend methods which without being financially prohibitive will nevertheless practically eliminate the damage from electrolysis."

The following bodies are represented on the Committee by three members each:

American Institute of Electrical Engineers
American Electric Railway Association
American Railway Engineering Association
National Electric Light Association
American Gas Association
Natural Gas Association of America
American Telephone and Telegraph Company
American Water Works Association
National Bureau of Standards

In October, 1916, the Committee published "A Preliminary Report Prepared for Submission to its Principals." This report was in the main a statement of the status of the art upon that date. It contained four sections prepared by as many sub-committees, dealing with the following subject matter:

I. Principles and Definitions
II. Methods of Making Electrolysis Surveys
III. American Practice
IV. European Practice

[1] Consulting Engineer, of Crecelius and Phillips, Cleveland, Ohio.

The report was a compilation of methods, practices, and conditions, and included also to some extent such expressions of opinion and interpretation of the facts as could be agreed upon at that time. The report was not, however, in any sense the result of field research work by the Committee for the purpose of developing new facts regarding electrolysis and its mitigation.

Subsequent to the publication of its preliminary report, the activities of the American Committee on Electrolysis were interrupted by the war but were resumed early in 1919, at which time a new sub-committee was appointed, known as the Research Sub-committee, for the purpose of coöperating with the Bureau of Standards in conducting original research work. The earlier work of the Committee had demonstrated that there were fundamental differences of opinion as to the effectiveness of different methods of mitigation. One of these, and perhaps the most important, was pipe drainage. This in turn involved the question of joint corrosion and the Research Sub-committee forthwith undertook extensive investigations in many cities throughout the country for the purpose of determining upon the seriousness of joint corrosion and the conditions under which such corrosion took place. In the course of these investigations a great deal of valuable data was obtained, all of which was very thoroughly analyzed by the Research Sub-committee. From early in 1919 to date, the Research Sub-committee has actively prosecuted its investigations, and has held meetings as often as once a month.

The 1921 Report of the American Committee on Electrolysis supersedes the preliminary report in that it contains practically all of the subject matter contained in the earlier report and in addition contains the conclusions reached through the activities of the Research Sub-committee. The report represents the combined effort of all of the interests involved, including the Bureau of Standards and the unanimous opinion of the representatives of these different interests. The report is a very complete treatment of the subject and is in effect a treatise on electrolysis.

ABSTRACT OF 1921 REPORT

It is not possible within the limits of a review of this kind to completely abstract this comprehensive report. In lieu of this the principal differences between the 1916 and 1921 reports will be mentioned and the outstanding features of the latter report abstracted.

Chapter I, "Principles and Definitions" and Chapter IV, "European Practice" are substantially the same in both reports. On account of the war, European practice regarding electrolysis has not changed in any essential respect since the preliminary report was written. Chapter III, "Electrolysis Surveys" of the 1921 report contains a description of methods for determining the "leakage resistance between tracks and underground structures," or in other words, roadbed resistance. This resistance is a matter of first importance in track and roadbed construction. There is a rather wide difference in the roadbed resistance of the different types of construction which are now commonly used by electric railways. The higher resistance obtained by the use of wood ties with clean crushed stone, for example, substantially reduces the amount of stray current resulting from a given potential drop along the tracks, and consequently results in a saving in the cost of other mitigative measures.

Chapter II, "Design, Construction, Operation and Maintenance" of the 1921 report corresponds to Section III, "American Practice" of the 1916 report. The principal differences between the two reports are to be found in this chapter which is much more complete in the 1921 report, largely as a result of the investigations of the Research Sub-committee. This chapter contains a "Summary of Good Practice" which, in a space of eight pages, admirably but briefly sets forth the outstanding features of design and operation as regards both railways and affected structures, which today reflect the highest status of the art. This "Summary of Good Practice" constitutes a distinct contribution to the engineering profession and should prove of more than considerable value to the practical operating man who is confronted with the difficulties of electrolysis. This summary will be outlined in some detail.

The first section of the summary entitled "Railways" deals with the following subjects: (1) Track Construction and Bonding; (2) Track Insulation; (3) Reinforcement of Rail Conductivity; (4) Power Supply; (5) Interconnection of Tracks; (6) Insulated Negative Feeder System; (7) Three-Wire System; (8) Reversed Polarity Trolley System; (9) Periodic Reversal of Trolley Polarity; (10) Double Contact Conductor Systems; (11) Alternating Current Systems. The importance of making the tracks a continuous and low-resistance return circuit is set forth. This is accomplished by the use of heavy rails, properly bonded or welded joints, frequent cross-bonds, and jumpers around special work. The report states

"Roadbeds should be constructed with as high electrical resistance to earth as consistent with other considerations, special attention being given to keeping them dry by drainage. Where practicable, rails should be kept out of contact with the earth." With regard to the reinforcement of rail conductivity, the use of copper in parallel with tracks is shown to be uneconomical and the use of buried conductors to be undesirable because of reduced roadbed resistance. With regard to the reduction of stray currents by the proper design of the power distribution system of the electric railway, the report states,

(d) Numerous independent connections to the track for the return of current afford the most effective means of reducing high potential gradients and overall voltages and thereby limiting stray currents, and as many should be provided as consistent with good engineering and economic considerations.

This can be accomplished by the use of additional power supply stations, by the installation of insulated negative return feeders, or by the three-wire system wherein each car on the negative trolley becomes a point of return. Combinations of these may also be employed.

(e) The most generally satisfactory method of increasing the number of independent return points on a track system is by the use of additional substations and the tendency of railway practice is now in this direction.

(f) Considerable progress has been made in recent years in the development of automatic, semi-automatic, and remote control substations and these are now being used both on interurban lines and for city service. The economies attending such substations make possible a greater number of feeding points than can economically be supplied through manually operated stations.

(g) By employing the maximum number of substations consistent with economy, rather than the minimum number, stray currents will be greatly reduced.

The relatively high cost of returning power over an insulated negative feeder system as compared to the track and ground return is pointed out.

Under the heading "Affected Structures," the summary deals with the following subjects: (1) Location with Respect to Tracks; (2) Avoidance of Contact of Cables with Pipes and Other Structures; (3) Conduit Construction; (4) Insulating Joints in Cable Sheaths; (5) Surface Insulation of Pipes and Cables; (6) Insulating Joints in Pipes; (7) Shielding. It is pointed out that

On streets in positive areas where car tracks exist gas and water mains are sometimes installed on both sides of the streets. Such construction permits the use of shorter services and obviates the necessity for placing service pipes under tracks.

Of particular interest to pipe-owning interests is the Committee's conclusion regarding the use of insulating joints:

(a) Insulating or high resistance joints, such as those of the Dresser type or cement joints, if used throughout a pipe line at frequent intervals, or at specially selected locations may afford substantial protection against electrolysis. This practice relates particularly to gas and oil pipes.

(b) It is sometimes permissible to use comparatively few insulating joints if care is taken to see that the flow of current on the pipe is practically eliminated.

(c) Insulating joints are often installed in service pipes for the purpose of preventing the interchange of current between pipe systems.

The third section of the summary "Interconnection of Affected Structures and Railway Return Circuit" deals with (1) Cable Drainage and (2) Pipe Drainage. The essential difference between cables and pipes in so far as electrical drainage is concerned lies in the electrical continuity of cables and in the occurrence of high resistance joints in pipes. The rules governing the employment of cable drainage are set forth in considerable detail. With regard to pipe drainage, it is worth while to quote from the summary in full.

(a) There are wide differences of opinion among competent engineers who have studied pipe drainage, as to it adaptability to various conditions. Numerous questions are involved in regard to which there is not sufficient information available at the present time to permit the drawing of accurate conclusions, and for this reason this subject is being investigated by the Research Sub-Committee of the American Committee on Electrolysis. There are, however, certain objections to the use of pipe drainage which are discussed in this report and which should be carefully considered before employing it.

(b) Pipe drainage is in use more or less on water systems and to a limited extent on gas systems.

(c) As a method of mitigation, drainage is not so well adapted to pipes as to cable sheaths.

(d) High resistance joints are prevalent in all jointed pipe lines and they greatly complicate the application of drainage.

(e) To lower the potential of a jointed piping system below that of the surrounding earth, it is usually necessary to extend the drainage conductors over a considerable area and connect to the pipes at numerous locations.

(f) Corrosion at high resistance joints in pipe lines carrying current may occur unless the pipe on both sides of the joint is maintained negative or neutral to the adjacent earth, in which case no corrosion will occur.

(g) Drainage generally increases the current flow on pipes and such current increases the hazard from oil and gas ignitions and explosions.

(h) In small towns on interurban railways pipe drainage is less objectionable than in urban districts where complicated pipe networks exist.

(i) Drainage of a large network of pipes should be used only as an auxiliary to a railway system, properly designed and maintained from the electrolysis standpoint. When so used it should be installed and maintained under competent supervision.

It is perhaps desirable to repeat here that the foregoing is in no sense a comprehensive abstract of the report and that only a few of the outstanding questions dealt with in the report have been mentioned here. It is not putting it too strongly to say that everyone interested in the involved subject of electrolysis mitigation should find this 1921 Report of the American Committee on Electrolysis profitable reading and of great practical value.

Note: Copies of the Report may be had from the American Water Works Association, 153 West 71st Street, New York City, price $1.00, postage prepaid.

CHLORINE TASTES AND ODORS FROM PIPE COATING[1]

By E. J. Rowe[2]

I was very much interested in the article by C. A. Hechmer on the probable formation of phenolic compounds by a chlorinated water in contact with a coal tar paint.[3]

During the past three months I had a similar experience, and had drawn a similar conclusion, yet have been afraid to mention the same for fear of ridicule.

We put a million gallon rapid sand filter plant into operation the first of December, 1921. Owing to the lack of proper chlorine control equipment, a home-made device was used for about two weeks, consisting of a needle valve on the chlorine tank to control the feed. The chlorine passed through a rubber tube to a large and heavy wash bottle having a two-hole rubber stopper in the top, glass tubes were put through the stopper, one with the end restricted to a very small opening and long enough to reach nearly the bottom of the bottle for the chlorine and the other, much larger, connected to a clear water supply just long enough to enter the bottle through the stopper. The resulting solution was fed out through the side neck to a rubber tube extending to the bottom of the clear well ending in a large pan of very fine sand to act as a diffuser. This equipment was original with the writer and was in use at our slow sand filters for about four months. We were able to secure remarkable control in this manner, after a bit of experimenting to secure the proper adjustment of the needle valve. The chlorine would issue in small bubbles from the longer tube in plain sight. Our records show that less than $\frac{1}{16}$ pound

[1] The Editor calls particular attention to the above contribution as an example of the type of important material which frequently never sees the light of day. The author confesses his fear of ridicule, but at least in this instance he overcomes his diffidence. It is hoped that this paper will serve as a beacon to many water works superintendents who hide their "lights under a bushel" and will serve to elicit many contributions of data which have a value too often minimized by their collectors or originators.

[2] Superintendent, Water and Light Department Wellsville, New York.

[3] See Journal, March, 1922, page 319.

variation of chlorine fed from day to day, when applying 3 to 3½ pounds per day, determined by weighing the drum twice a day.

After the expiration of the above two weeks, proper equipment was installed to apply the chlorine.

When the complaints about the use of chlorine were being received the first two weeks, the writer attributed them to the crude method of applying the chlorine and let it go at that, but after a one-week trial with proper equipment, using a dose not to exceed 0.3 p.p.m., the complaints of chlorine tastes could be heard 16 miles southwest of Havana.

The point of application of chlorine was then changed to a point between the sedimentation basin and the filters. This did not correct the trouble, or rather stop the complaints. The writer then attributed the complaints to organic compounds or deposits that had been accumulating in the system during the past thirty years, emphasized, no doubt, by the somewhat liberal dosage of chlorine and the flushing of the hydrants. The somewhat unusual point, however, regarding the complaints was the fact that it (the "chlorine ghost") showed up in spots around the system. This system is well designed to give the greatest possible circulation with no dead ends that could be avoided. The writer lives at such a point that practically all the water used must pass his residence before reaching the major portion of the town, yet at his residence he could detect no trace of excess chlorine, except on two different occasions, about five weeks apart. In following up the "chlorine ghost" it would seem to be no respector of either rapid or slow circulation of the water in the mains. Apparently the taste travelled in slugs, as in several cases the objectionable taste and odor would disappear within an hour or two. Several times the writer made special trips in response to telephone calls only to find that the "ghost" had faded away before his arrival. This happened several times when the calls had come from reliable parties. Is it any wonder the writer called it the "chlorine ghost"?

When it was run into a corner and finally captured, the writer found, not the characteristic chlorine odor and taste, but "one closely resembling that of iodoform and the taste approached that of carbolic acid" (if I may be permitted to quote the article mentioned).

This fact had the writer puzzled until a few days later, about January 20, when, in making an inspection of the discharge end of the force main (12-inch C. I. pipe from the filters to the storage basin) he noticed a deposit of brownish black flakes, somewhat similar to

flakes of iron rust. Upon picking up a handful the "chlorine ghost" odor was very marked.

A sample of this deposit was taken to the laboratory and studied. The writer concluded it was the coating from the pipe which had been laid about seven years previously, as a sample taken from the coating of the piping system of the new filter plant would not give the same reactions as from the older pipes. It had all the characteristics of a phenol compound combined with iron. The sample of the deposit was treated as follows (simply because the writer didn't know of any other method to test the stuff). A flake was placed in six flasks and about 100 cc. of distilled water was added. The flasks were then placed, two in the 37° incubator, two on a bench in the laboratory, two in a cold water bath, the temperature of the same being about $\frac{1}{4}$ to $1\frac{1}{2}$°C., resulting in no perceptible taste or odor after three days. At the end of this period one drop of a saturated solution of chlorinated lime was added to one of each pair of flasks, when the odor of iodoform was noticed in about two hours (may have developed earlier) in the flask at 37°, no odor at lower temperature, this odor disappearing within six hours or just about the time it appeared at the lower temperature. The odor persisted at the lowest temperature for more or less than a day, while the taste remained after the disappearance of the odor for over twenty-four hours. The samples not treated with chlorine showed no deposits, odor or taste after two weeks. The sample at 37° was kept in the incubator until all the water had evaporated. The flake was re-treated with distilled water and returned to the incubator for four hours. No taste or odor developed. When placed in a cold water bath, no taste or odor resulted within four hours, but upon adding an additional drop of chlorine solution about $\frac{1}{10}$ the strength of first solution, the odor and taste of the "chlorine ghost" were very pronounced after four hours.

The only suggestion that the writer can offer is that the chlorinated water standing in this force main (the plant being in operation about twelve hours a day) caused a formation of some phenolic compound which required a time element to form. From the experiments this period seems to be from one to six hours. It is suggested that it would be worth while to investigate the question of pipe paints or coatings, especially when used to convey chlorinated water, as three months use of this particular pipe line has not neutralized this objectionable feature. Any dosage above 0.3 p.p.m. will cause the appearance of the chlorine taste even when it is impossible to detect any excess chlorine.

WATER SUPPLY LEGISLATION IN OHIO[1]

By W. H. Dittoe[2] and F. H. Waring[3]

HISTORICAL

In 1886, the legislature of Ohio enacted a law creating the State Board of Health. Ohio was the thirty-second state in the Union to provide for a state health department. Although engineering problems involving water supply and sewerage soon arose, there were no laws to provide control of public water supply and sewerage improvements until 1893. The legislature in that year passed a law requiring the submission of plans for proposed public water supply and sewerage improvements to the State Board of Health for approval. This law is codified as section 1240 G. C. The first projects submitted to the State Board of Health in compliance with this law were passed upon by members of the board and its secretary; no engineering personnel was employed.

A general examination of public water supplies in Ohio was taken up in 1897 and members of the faculty of the Ohio State University were retained for this purpose. The investigation showed that some provision should be made for regular examination of public water supplies. Accordingly in 1898, the legislature passed a law providing for the annual investigation and report of the conditions of all public water supplies. It was following this enactment that provision was made for a division of laboratories and a division of engineering attached to the State Board of Health. For the period up to 1901 only one engineer was employed to carry on the work.

In 1906, an act of the legislature directed the State Board of Health to investigate the construction, operation and efficiency of water purification and sewage treatment plants in Ohio and to

[1] Read before the meeting of the Central States Section at Columbus, September 27, 1921.

[2] Chief Engineer, State Department of Health, Columbus, Ohio.

[3] Principal Assistant Engineer, State Department of Health, Columbus, Ohio.

report to the legislature by March, 1908, with recommendations. Special assistant engineers were employed in this work, which was carried on for approximately two years.

In 1908, a law was passed based upon the results of investigations of the water purification plants and the sewage treatment plants. This law, known as the Bense Act, was amended later and reënacted in 1919. It is codified under sections 1249 to 1261 inclusive, G. C. It was not until 1912 that this law became fully effective when the Supreme Court of Ohio decided upon its constitutionality.

The Ohio Building Code was enacted in 1911. This includes the plumbing code which gives to the State Department of Health duties of enforcing certain provisions. In 1913, the legislature authorized the establishment of sewer districts by county commissioners in which water supply and sewerage improvements could be made in areas outside of incorporated municipalities.

In 1919, the Sanitary District Act was passed. Under the provisions of this act a district may be organized for the purposes of water supply and sanitation without reference to political boundaries of the areas affected, that is to say, the area shall include two or more political sub-divisions or portions thereof, without reference to contiguous territory or without necessity of the area being entirely within one county.

In 1920, the State Department of Health adopted regulations in accordance with the provisions of section 1240 and the building code setting forth in detail the exact manner in which plans for water supply and sewerage improvements should be submitted to the department for approval before contract work was undertaken. Such regulations were for the purpose of assisting the engineers in planning improvements, as well as to prevent misunderstanding on the part of municipalities and corporations as to the extent of jurisdiction of the State Department of Health over proposed work. The regulations were made to cover a broader field, including improvements for semi-public and quasi-public places such as factories, hotels, summer resorts, etc. The expansion of the duties of the health department under the regulations adopted in 1920 was with the effort to obtain a closer check upon the kinds of installations made for public purposes.

It should be pointed out in this connection that the power of the State Department of Health to protect the public health was limited. For example, many installations of water supplies were made prior

to the regulations of 1920 and the original code of 1893. Defects were noted in such systems from time to time in the course of routine inspections carried on by the engineering division. The municipal authorities were advised in such cases to make the corrections, many times the correction being so simple that direct advice could be given as to the manner of correcting the fault. If the municipality chose to disregard the advice, no direct action could be taken to bring about the changes deemed necessary to protect the public health. The Salem, Ohio, typhoid fever epidemic was directly attributable to the existence of poor development of the public water supply system. The particularly objectionable points had been brought to the attention of the municipal authorities as early as 1900. Again in the case of the Hillsboro, Ohio, epidemic of 1920 and 1921, the trouble was caused by the use of an emergency intake whereby polluted creek water was introduced into the water supply mains, after the State Health Department had repeatedly advised, as late as 1919, that the maintenance of such an intake constituted a grave menace to the public health.

The lessons of the Salem and Hillsboro epidemics were brought home so forcibly upon the general public that a new and much more drastic power was delegated to the State Department of Health by an act of the legislature in 1921 under the title of House Bill No. 266. A brief description of this legislation is of interest to the water works officials not only in Ohio but in other states since attempt is made to fix responsibility upon a central authority for the safeguarding of the public water supply systems of the state through its health department.

WATER SUPPLY LEGISLATION OF 1921

The title of the enactment reads: "To provide state supervisory control of public water supplies and to empower the State Department of Health to require improvement of unsatisfactory water supply and water works systems." The act comprises six sections codified as sections 1252–1 to 1252–6 G. C. A brief description of each section will be given.

Section 1 (*sec. 1252-1 G. C.*). This section requires the State Department of Health to exercise general supervision over the operation and maintenance of the public and quasi-public water supplies throughout the state. Such general supervision entails the following duties:

1. Investigations of the water supplies at regular intervals and *whenever requested by local health officials.*

2. Preparation for adoption of orders and regulations of a more or less general character, regarding operation and maintenance of water supply systems.

3. Preparation of forms for the submission of reports of operation.

4. Prompt examination of such reports and follow up of same.

Section 2. (*sec. 1252-2 G. C.*). This section requires regular analyses of each public water supply in such manner and at such intervals as may be ordered by the State Department of Health. The proper enforcement of this section requires very careful thought to reach satisfactory conclusions on the following points:

1. Collection of samples: (*a*) sampling points, number and location; (*b*) by whom to be collected; (*c*) source and character of container to be used.

2. Frequency of examination of samples for each particular water supply.

3. Determinations to be made as a regular procedure.

4. Methods of analyses to be followed.

5. By what laboratories analyses are to be made. Laboratories may be subdivided as public and private, and the public laboratories may be further subdivided as local health department laboratories and water purification plant laboratories. A complete list of all available laboratories in the state must be compiled.

6. Adoption of a form for record and report of results of analyses.

7. Determination of method of submission of report to State Department of Health.

Section 3 (*sec. 1252–3 G. C.*). This section makes unlawful the establishment of a cross-connection with a public water supply system unless such connection has been approved by the State Department of Health. This section will result in submission of many requests for action and will require a considerable amount of work to answer and dispose of such requests.

Sections 4 and 5 (*sec. 1252–4, 1252–5 G. C.*). These sections empower the State Department of Health to order improvements in water supply systems which are found necessary to provide safety. Investigations will be at the initiative of the department. The procedure to order corrections or improvements and the enforcement of the order is delegated to the statutes already enacted by the Bense Act as recodified in 1919. The law clearly imposes, therefore, upon the

department a responsibility for finding out defects, in water supply systems, reporting upon them, and securing their correction. This means that each examination of a water supply system must be a complete one, otherwise the department will be charged with oversight and neglect of duty.

Section 6 (*sec. 1252–6. G. C.*). This section provides that whoever violates any provisions of sections 1, 2 or 3, shall be deemed guilty of a misdemeanor and subject to fine.

It is apparent that the proper enforcement of the provisions of the recent legislation will not be secured fully until additions to the personnel of the Division of Engineering are made, since the discharge of the duties already imposed by law upon the Division, prior to the enactment of the House Bill No. 266, require the constant effort of the sanitary engineers as at present constituted. This matter was called to the attention of the legislators and assurance was given that proper provisions to carry on the extra work would be forthcoming in the near future. The new legislation became effective August 18,1921.

THE CAUSES OF OBNOXIOUS TASTES AND ODORS SOMETIMES OCCURRING IN THE CLEVELAND WATER SUPPLY[1]

By J. W. Ellms[2] and W. C. Lawrence[3]

Consumers of the Cleveland water supply have been troubled from time to time for a number of years with obnoxious tastes and odors in the water. The taste and odor complained of is described as "medicinal" or like chlorine or carbolic acid. The taste is particularly offensive in hot water or in tea made with it. The taste is not usually complained of for more than a few days at a time, indicating that the contamination is intermittent. Complaints are more frequent following ice movements in the lake, during the early spring months, than at other times, although high winds, which agitate the lake and set up unusual surface and subsurface currents, appear to be in some way related to the recurrence of these tastes.

The authors have been investigating the problem for several years and have come to the general conclusion that the taste was related in some way to trade wastes discharged into the Cuyahoga River and from thence into the lake, and that the chlorination of the water supply brought out or developed the foul taste.

The Cuyahoga River flowing through the heart of the city is lined along its banks for miles with manufacturing plants of varied character. The stream is not a large one and has a low current velocity, especially through the manufacturing district. Consequently it is hardly more than a lagoon of the lake, rising and falling with the changes in the lake level. The stream is badly polluted, receiving besides trade wastes, a large proportion of the domestic sewage of the valley district.

The two water works intakes of the city are approximately 4 miles north of the mouth of the Cuyahoga River. One intake is a submerged crib, and the other is a steel crib with superstructure. They

[1] Presented before the Cleveland Convention on June 7, 1921.

[2] Engineer of Water Purification, Water Department, Cleveland, Ohio.

[3] Chemical Engineer, Water Department, Cleveland, Ohio.

are located within 3700 feet of each other in about 50 feet of water. Reference to the map will show the relative positions of the intakes, mouth of river, outfall sewers on lake front, and the sumerous sampling points located on the Cuyahoga River.

SAMPLING POINTS

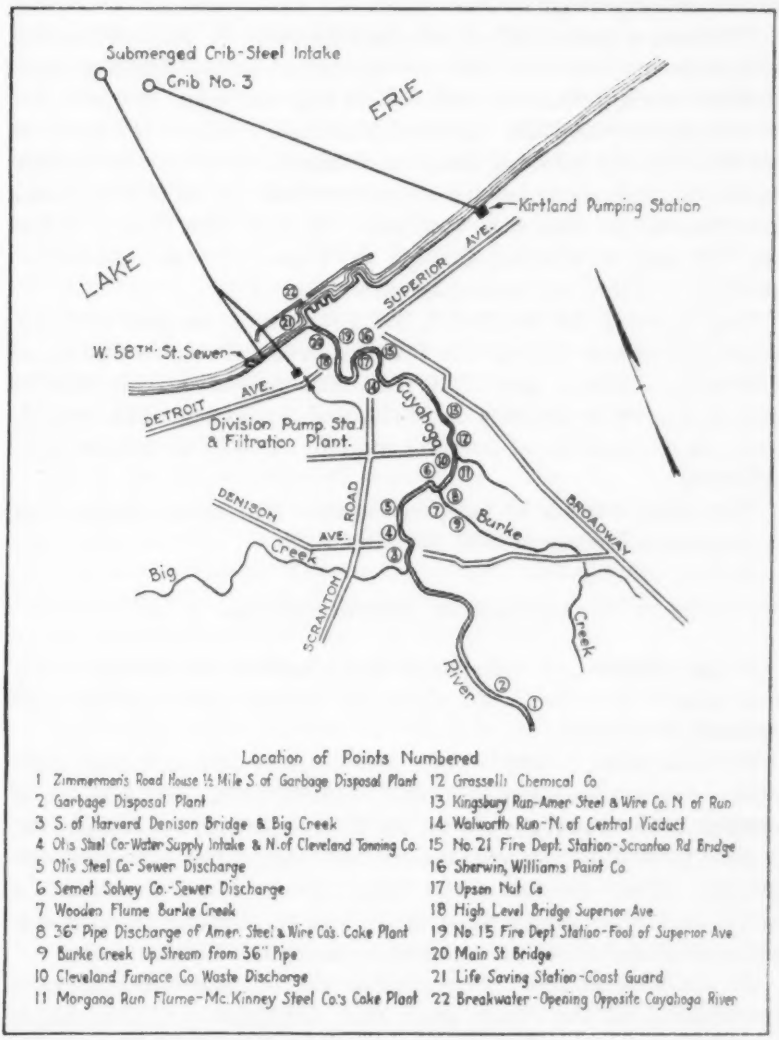
It was decided at the beginning of 1920, to sample systematically for a time (1) the water of the Cuyahoga River at selected points for a distance of several miles up the stream, (2) the sewage discharging from the West Fifty-eighth Street sewer outfall on the lake front, and (3) the lake water coming through the two water works intakes. It was hoped that, by sampling at a large number of points, the original source of the waste producing the foul taste in the lake water might be located more definitely. By elimination we succeeded in locating the sources of the wastes primarily responsible for the obnoxious tastes in the water supply.

The active sampling was carried on during the first three months of the year or prior to the breaking up of the ice in the lake. Some of the samples were collected later in the year, principally to confirm, if possible, by direct chemical tests, our earlier work.

Between January 7 and April 1, 1920, 719 sewage and river samples were collected. Of this number, 216 were taken from the mouth of the West Fifty-eighth Street sewer. This sewer collects the sewage from quite an area on the west side of the river, including a large number of industrial plants.

From the Cuyahoga River, 120 samples were taken near the mouth of the river opposite the U. S. Coast Guard Life Saving Station; 95 samples from Cleveland's Fire Station No. 21, located on the Cuyahoga River at West Third Street; 82 samples from Cleveland's Fire Station No. 15, located on Superior Avenue; and 206 samples from various sewer outfalls on both sides of the stream, and from the channel of the river. Samples of the river water were collected as far south as the Cleveland garbage disposal plant at Willow, Ohio, but the samples collected with the launch were taken only as far south as Burke Creek, a distance by river of 5.6 miles from the mouth of the stream. Burke Creek was as far as it was possible to take the launch on account of the shallow water in the river. This creek, however, receives considerable sewage from territory still further south.

Samples from the mouth of the West Fifty-eighth Street sewer, the mouth of the river opposite the Life Saving Station, and Fire Stations



Location of Points Numbered

1 Zimmerman's Road House ½ Mile S. of Garbage Disposal Plant
2 Garbage Disposal Plant
3 S. of Harvard Denison Bridge & Big Creek
4 Otis Steel Co-Water-Supply Intake & N. of Cleveland Tanning Co.
5 Otis Steel Co-Sewer Discharge
6 Semet Solvey Co.-Sewer Discharge
7 Wooden Flume Burke Creek
8 36" Pipe Discharge of Amer. Steel & Wire Co's. Coke Plant
9 Burke Creek Up Stream from 36" Pipe
10 Cleveland Furnace Co Waste Discharge
11 Morgana Run Flume-Mc. Kinney Steel Co's Coke Plant
12 Grasselli Chemical Co
13 Kingsbury Run-Amer Steel & Wire Co. N. of Run
14 Walworth Run-N. of Central Viaduct
15 No. 21 Fire Dept. Station-Scranton Rd Bridge
16 Sherwin, Williams Paint Co
17 Upson Nut Co
18 High Level Bridge Superior Ave
19 No 15 Fire Dept Station-Foot of Superior Ave
20 Main St Bridge
21 Life Saving Station-Coast Guard
22 Breakwater-Opening Opposite Cuyahoga River

FIG. 1. LOCATION OF SAMPLING POINTS

Nos. 15 and 21 were taken three times daily, at 8:00 a.m., 4:00 p.m. and 12:00 p.m. for a portion of the first three months of the year. Late in the year a large number of special samples were taken on

inspection trips of practically all of the manufacturing plants discharging sewage and trade wastes directly into the river as far up the stream as the garbage disposal plant.

Following a movement of the lake ice early in January, a trip was made out into the lake to the intake cribs. Samples were collected during the entire trip. This trip was made out into the lake on January 10, 1920. Later on March 24, another trip was made out into the lake following the ice as it moved away from the harbor entrance. Samples of ice and water were collected at this time and some instructive data were obtained. On these two trips a harbor tug was used in breaking through the thinner ice near the harbor entrance. A total of 58 samples was collected.

From January 13, to April 1, 1920, raw water samples were collected three times daily at the Division Avenue Pumping Station at 8:00 a.m., 4:00 p.m. and 12:00 p.m., and one sample daily at 8:00 a.m. beginning on January 22, 1920, and continuing until April 1, from the Kirtland Street Pumping Station. In all, 242 samples were collected.

The total number of samples collected and tested during this investigation is between 1000 and 1100.

METHODS OF TESTING SAMPLES

It had always been recognized that whatever the substance was that caused the tastes in the water, the amount thereof present was probably very small.

In the absence of any definite knowledge of this substance, little could be done in the way of specific chemical tests. The addition of chlorine to the water, even in the small amounts used for disinfection, seemed to be able to develop the offensive taste if the substance were present. Hence the use of the "taste or odor test," after addition of chlorine, was decided upon as the test to establish the probable presence or absence of the compound causing the offensive taste.

It was obvious at the beginning of this investigation that some modification of the "taste test" after chlorination of the sample would have to be followed with the sewage and foul river water. Some changes were also found necessary in applying the test as first developed.

During the first month (to February 9, 1920), the method of testing the sewage and river samples was as follows:

A definite amount of chlorine was added to each sample, the quantity of chlorine being sufficient to leave free chlorine in the sample after standing eighteen hours, and to have disappeared in twenty-four hours. The odor was then noted in the cold sample. A portion of the sample was next boiled and the odor noted while hot, and after it had cooled. This treatment after February 9, 1920 was modified, so that a 250-cc. portion of the sample was treated with a moderate excess of chlorine and boiled until no free chlorine could be detected. The odor was then noted after the sample had cooled. It is of interest to state here that a few of the samples gave evidence of the presence of chemical compounds which interfered with our ascertaining whether the water was free from chlorine or not as they gave positive reactions with the starch-iodide test before treatment with chlorine. It also seemed necessary to add enough chlorine to oxidize certain constituents of the water before the odor sought could be detected. Moreover, an excess of chlorine, if not entirely removed, masked the odor as well.

Boiling the sample drove off some of the other odors in the water and brought out more prominently, when present, the characteristic odor being sought. Boiling did not always drive off the excess chlorine or the chlorine compounds formed. An attempt to reproduce the original characteristic odor in samples a month old by a second treatment with chlorine was unsuccessful.

In those samples of water from the lake which it was safe to taste, the procedure was as follows:

Five hundred cubic centimeter portions of each sample were treated with about 0.1 p.p.m. of chlorine. The samples were allowed to stand twenty-four hours and the taste was noted. A portion of the treated sample was then boiled, cooled and again tested by tasting. Beginning February 7, 1920, an additional quantity of chlorine (about 0.5 p.p.m.) was added to the portion of the sample that had already been treated, allowed to stand twenty-four hours, a portion boiled, cooled and the taste noted. They were not tested in the cold because the cold samples, even after standing twenty-four hours, were at times found to contain free chlorine. Some slight modifications of this procedure were at times necessary, when oil or other polluting matter in the lake water samples collected near the harbor entrance required larger quantities of chlorine, longer boiling or both methods of treatment.

In order to learn whether the obnoxious taste could be duplicated, and if a verification of the delicacy of the taste and odor tests used in this work could be obtained, experiments with dilutions of pure phenol (carbolic acid) in distilled water were made. It was possible to detect the taste of 1 part of pure phenol in 25,000 parts of distilled water with a considerable degree of certainty. Dilutions as high as 1 part in 50,000 parts of water could not be detected.

By chlorinating dilutions of pure phenol in water and then removing all excess of chlorine, it was easily possible to detect as little as 1 part of the chlorinated phenol in 5,000,000 parts of water. So similar and characteristic are the odor and taste of these chlorinated products, that once a person has smelled or tasted them, he is not likely ever to forget them.

The offensive odor and taste appearing at times in the public water supply are precisely the same as those produced by chlorinating pure carbolic acid. The extraordinarily small quantities of the chlorinated phenols that are capable of imparting characteristic odor and taste to water explain how easily a relatively small proportion of trade wastes containing phenolic compounds may contaminate vast volumes of the lake water. Whenever the lake water thus polluted passes into the City's intakes the presence of phenolic bodies immediately becomes evident when the water is chlorinated, in the usual course of its purification for public consumption.

DIRECT TEST FOR CARBOLIC ACID

Late last fall there was brought to our attention a delicate test for very small amounts of phenol (carbolic acid) in water. We secured the necessary chemicals to prepare this reagent and have been able to apply it to some of the samples collected early in the year, as well as to use it on some samples recently collected from the Cuyahoga River, and from waste liquors from certain industrial plants. We have found it is a very sensitive test for phenol, but unfortunatly it is also a delicate test for certain other substances. The reagent is a complex mixture of phosphotungstic and phosphomolybdic acids. In a sample of water made strongly alkaline with sodium carbonate this greenish colored reagent produces a blue color in a water containing carbolic acid. Hydrogen sulphide, ferrous iron and cuprous copper will also react with this reagent. Since at least the first two of these compounds are quite likely to be present in polluted waters, the value of the test for this work is doubtful.

RESULTS OBTAINED

It is hardly necessary in this paper to give in detail the results obtained during this systematic survey of river and lake conditions. Over 1000 samples were collected and tested. A summary of the positive characteristic taste or odor results obtained during the investigation is as follows:

SAMPLE TAKEN FROM	TOTAL NUMBER SAMPLES TAKEN	NUMBER POSITIVE
West 58th Street Sewer	217	0
Cuyahoga River at harbor mouth	121	3
Cuyahoga River Fire Stations Nos. 15 and 21	177	9
Water Works intakes	242	121
Lake Erie between harbor mouth and intake	61	25
Cuyahoga River and sewer outfalls into river	221	46
Lake from 1 to 7 miles north of intakes	5	0
Total number of samples	1044	204

DISCUSSION OF RESULTS AND CONCLUSION

The continuous testing of the lake water entering the intakes together with the testing of the river samples, established a relation between the two which was considered especially significant. The results of two lake trips in a tug following ice movements were of special interest, as they indicated the part the ice plays in disseminating polluted matter, and also because of the fact that, on one trip, it was possible to trace the "taste producing material" from the mouth of the Cuyahoga River directly to the area around the intakes of the water works. Coupling this fact with another brought out by the river work, namely, that the same waste material was found to be present in the river water for at least 5 or 6 miles from the harbor entrance, it is possible to present a complete line of evidence, which showed that the polluted water of the Cuyahoga River reached the water works intakes, and that this polluted water contained the material which caused the obnoxious taste. It will also be noted that not a single sample from the West Fifty-eighth Street sewer outfall produced, when treated with chlorine, the characteristic taste.

Of 398 samples collected in the Cuyahoga River and above the mouth of the stream, 55 gave positive tests. Of the 182 samples at the mouth of the river, and between the latter and the intakes, 28

gave positive tests. Of the 242 samples which came through the intakes, 121 or 50 per cent, gave positive characteristic taste. Five samples taken on a single day from one to seven miles north of the intakes gave negative results.

The period covered by the greater number of these tests was during the winter months when the lake contains considerable quantities of floating ice. These ice floes are moved about by the wind. In their movements back and forth in front of the mouth of the river they act like gigantic mixing paddles, stirring and mixing the polluted river water into the lake water. The ice at the mouth of the stream also becomes badly polluted, as our observations showed. As it breaks up or is carried out bodily by floes sweeping by, it may and probably does carry pollution directly to the intakes.

The significance of the positive results obtained in following out the floating ice on a tug on March 24, 1920, is, as previously noted, of great importance, as it links the polluted river water directly with the water which must have found its way into the intakes. Associating this fact with the unquestionably positive results obtained from samples from the Cuyahoga River, and from sewers or polluted creeks discharging into the stream, no doubt remains in the minds of the authors as to the source of the offensive material which at times gets into the public supply.

If the line of positive samples taken from the Cuyahoga River is traced up the stream, it is apparent that no sample containing the offensive odor and taste producing material was obtained above the sewers discharging near the Wheeling and Lake Erie Bridge across the Cuyahoga River. There is, however, an industrial plant further up the stream, which discharges certain of its trade wastes through Burke Creek. The latter empties into the river below the Wheeling and Lake Erie bridge referred to above. This Burke Creek water, when chlorinated, was always shown to be polluted with the material producing the obnoxious taste.

Further down the stream are sewers from another large plant which discharge into the river, and from which positive tests were frequently obtained. It was also true that samples of river water, taken below this latter plant, frequently gave positive tests. Sometimes samples from sewers from plants, which used river water for cooling purposes were obtained, which gave positive tests, but in these cases it seemed more than probable that the river water contained the trade waste before being pumped into the plant using it. Further investigation

of a large number of industrial plants along the stream, by inspecting their processes, and by securing and testing samples of sewage or waste before they were discharged from the works into the river, demonstrated that those processes producing wastes, which after chlorination caused the obnoxious taste, were derived from plants engaged in the destructive distillation of coal.

Reference to figure 2 will show some of the products derived from the distillation of coal, and the further distillation of gas liquor and tar. From the gas liquor ammonia and ammonium salts are obtained. This liquor, which is of considerable volume, is concentrated in stills, in which lime is used to separate the ammonium compounds. The concentrate from such stills is wasted. We have never failed, with but one exception, in obtaining the characteristic "carbolic taste and odor" from chlorine treated samples of this waste. Crude carbolic acid is a by-product found in fractioning the tar into light, middle and heavy oils. Small amounts of phenolic compounds are doubtless present at all times in gas liquor, and hence may be present in the concentrate from ammonia stills. At one of the coke oven plants investigated, it was admitted that the waste liquor from their ammonia stills amounted to as much as 40,000 gallons daily.. The authors understand that the Waste Disposal Committee of the American Gas Association has been bending its efforts toward devising some method for caring for the concentrate from ammonia stills. It is our understanding that not only the condensed aqueous vapor from the tar main is sent to the ammonia stills but also any scrubbing water used in cleansing the gas. We examined a sample of liquor concentrate from ammonia stills, which came from a gas plant in one of the New England States. This sample reacted to all of our tests in the same manner as those samples taken by us from the by-product coke oven plants in the valley of the Cuyahoga River.

According to Thorpe[4] gas liquors always contain phenols, and in fact smell more or less strongly of them. This authority also states that gas liquors contain from 0.1 gram to 0.35 gram of phenol per 100 grams (0.1 to 0.35 per cent) of gas liquor. He further states that the waste liquors and lime sludges from ammonia stills always contain phenols, and that, on account of their offensive character, great difficulty in disposing of them is frequently encountered.

As a result of this investigation, the authors conclude that the cause of the obnoxious taste and odor, which at times occur in the

[4] Thorpe's Dictionary of Applied Chemistry, p. 144.

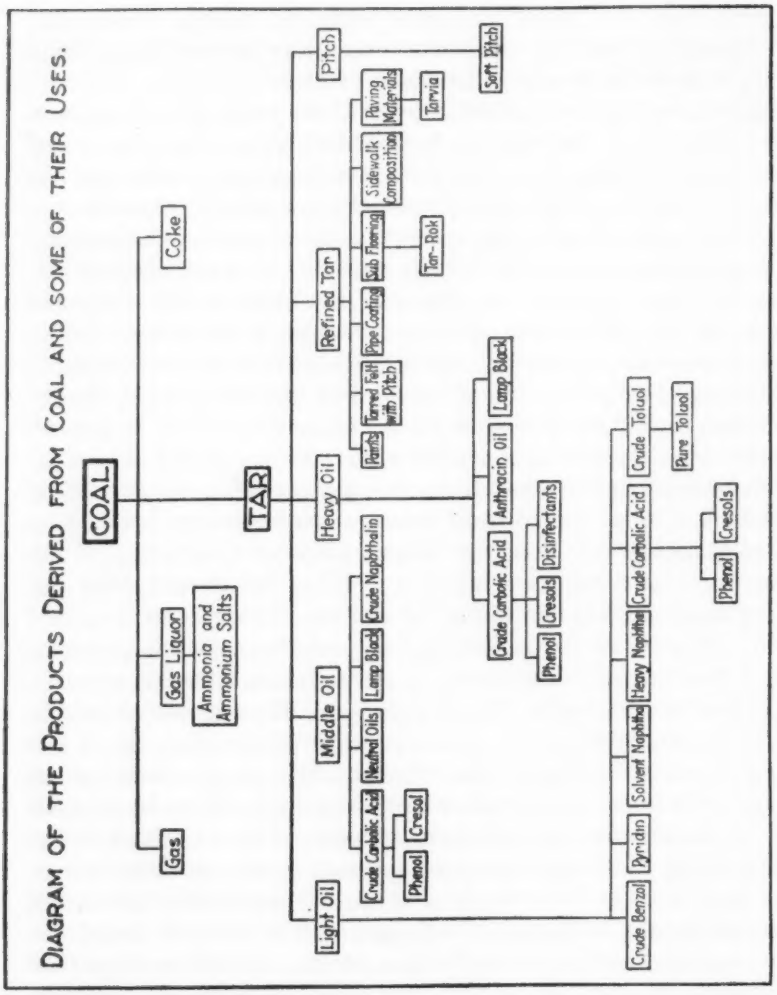


DIAGRAM OF THE PRODUCTS DERIVED FROM COAL AND SOME OF THEIR USES.
COAL
Gas
Coke
Gas Liquor
Ammonia and Ammonium Salts
TAR
Light Oil
Middle Oil
Heavy Oil
Refined Tar
Pitch
Crude Carbolic Acid
Neutral Oils
Lamp Black
Crude Naphthalin
Paints
Tarred Felt with Pitch
Pipe Coating
Sub Flooring
Sidewalk Composition
Paving Materials
Tarvia
Tar-Rok
Soft Pitch
Phenol
Cresol
Crude Carbolic Acid
Anthracin Oil
Lamp Black
Phenol
Cresols
Disinfectants
Crude Benzol
Pyridin
Solvent Naphtha
Heavy Naphtha
Crude Carbolic Acid
Crude Toluol
Pure Toluol
Phenol
Cresols

FIG. 2

public water supply, are due to trade wastes from the plants on the Cuyahoga River which are operating by-product coke ovens. The waste liquors and sludges from these plants, derived from the distillation of gas liquor for ammonia and ammonium salts, find their way through sewers and creeks leading into the river and are finally discharged into the lake. This polluted lake water moved about by the winds and ice finds its way into the intakes of the water works. When this water polluted with this waste is chlorinated, in the regular course of purification of the City's supply, a portion of the chlorine unites with the phenol and allied organic compounds, forming substitution and addition products, which are foul smelling and tasting. The original polluting material is in solution and cannot be removed by filtration.

The remedy for this trouble obviously is to prevent the discharge of the offensive trade wastes into the lake water. It is primarily a problem of trade wastes disposal and not water purification.

REMOVAL OF BACTERIA BY ZEOLITIC WATER SOFTENERS[1,2]

By Gerald C. Baker[3]

I. INTRODUCTION

There is a growing demand for soft waters for both domestic and industrial uses. The chief industrial uses are for laundries, boiler houses, dying plants, hair dressing establishments, etc. Since zeolitic softeners produce a water of zero hardness and are more economical and simple to operate than plants employing chemical and other precipitation methods they are rapidly gaining public favor.

The questions are often asked whether zeolitic softened water is more beneficial for drinking purposes than untreated water and whether such softened water is suitable for bottled drinks. Without entering into the question of the therapeutic values of different drinking waters, it suffices to say that all authorities agree that a good drinking water must be one which is safe bacteriologically. The question naturally arises then as to what, if any, sterilizing action these zeolitic filters have. Duggan (1) and Bencke (2) refer to a certain type of permutit as having a sterilizing action, while an anonymous article (3) claims that microbes are wholly removed when water is passed through it. With the exception of these references no additional information could be found on the subject. It was with the view of definitely establishing what sterilizing action common zeolitic water softeners possess, that this work was undertaken. No references at all were found concerning the use of zeolitic softened waters for bottled drinks.

[1] Read by abstract at the meeting of the Iowa Section, at Omaha, Nebraska, November 1, 1921.

[2] This work was carried out under the direction of the Department of Pathology and Bacteriology of the State University of Iowa.

[3] State University of Iowa, Iowa City, Iowa.

II. EXPERIMENTAL

(*A*) *Apparatus and materials*

In attacking the problem of the quality of zeolitic softened water for drinking purposes it was thought best to carry out not only laboratory experiments, but also to conduct tests upon domestic and industrial installations of the common water softening minerals on the market.

The laboratory experiments were carried out in specially prepared apparatus shown in the accompanying photograph.

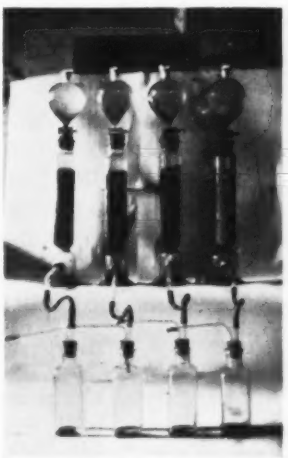


FIG. 1

Equal volumes (250 cc.) of previously used permutit, refinite, borromite, and sand were placed in 12-inch calcium chloride towers which were fitted with 250-cc. separatory funnels, which served as feed reservoirs for the water which was being filtered. The minerals in all cases were supported by a layer of glass wool. Siphon tubes led from the reservoirs of the calcium chloride towers to 250 cc. bottles. These bottles were supplied with glass outlet tubes, and served as receivers for the filtered water. After opening the stopcocks of the separatory funnels and plugging all openings with cotton, the apparatus was sterilized in an autoclave at 15 pounds pressure for thirty minutes. When thoroughly cooled the testing solutions were slowly passed through the minerals and samples collected aseptically for analysis.

Three domestic units and one commercial zeolite water softening installation were tested at irregular intervals. The domestic units comprised permutit, refinite and borromite installations situated in the basement of Close Hall of the University of Iowa and are intermittently operated. The commercial unit examined was a permutit filter in daily use by the New Process Laundry of Iowa City, Iowa. The domestic units in Close Hall are supplied by the University of Iowa water supply which is derived chiefly from deep wells, but which is supplemented at all times by a variable quantity of the Iowa City city supply. The New Process filter is fed by the Iowa City city supply which is derived from infiltration galleries beneath the Iowa River. The water is coagulated with alum and lime and is filtered through rapid sand filters followed by sterilization with liquid chlorine.

In order to test further the quality of zeolitic softened water for drinking purposes and its adaptability for use in bottled drinks an attempt was made to sterilize the filter bed of a domestic zeolitic softener with varying amounts of sodium hypochlorite, and tests were made on the filtered water to determine the quality of the water delivered. The most suitable type of softener for these tests seemed to be a domestic borromite installation, due to its simplicity of operation and the convenience of applying the sodium hypochlorite. The sodium hypochlorite could be added directly to the softener through the top opening at the same time as the salt used for the regeneration of the system. With the other types of zeolitic installations, which are reconditioned with a brine solution prepared outside the softener, it would be more difficult to control the amount of liberated chlorine supplied to the softener. The borromite system could be reconditioned in ten to fifteen minutes, whereas refinite and permutit softeners require six to nine hours for reconditioning. Sodium hypochlorite was used instead of bleaching powder for sterilizing the filter bed, since it would not add hardness to the filter. It was not thought advisable to use liquid chlorine.

Through the courtesy of the Borromite Company of Chicago, these tests were carried out in their laboratories using two D-9 type softeners and water from the Chicago city supply.

(*B*) *Methods of analysis*

The methods of analysis employed were those of the American Public Health Association, as outlined in "Standard Methods of

Water Analysis," 1920 edition. Counts were made at the end of forty-eight hours on plain agar and at the end of twenty-four hours on litmus lactose agar. The number of acid colonies on the litmus lactose plates was also recorded. Fermentation observations were made on 10-cc. and 1-cc. samples of water in lactose broth, at the end of twenty-four and forty-eight hours. All gas formation was confirmed on eosin-methylene-blue agar plates, incubated at 37°C. for twenty-four hours. The quality of the filtered water was judged according to the number of colonies produced on the agar plates and by the presence or absence of gas in lactose broth.

In the sterilization experiments bacterial counts were made as a check to determine the effectiveness of the hypochlorite treatment. These counts were made at room temperature (26°C) at the end of twenty-four and forty-eight hours on plain agar. The agar was supplied by the Chicago Health Department. Since the Chicago supply seldom contains gas formers, fermentation tests were not made as previous work had shown the entire absence of B. coli in zeolitic softened water, when the raw water was free from sugar-splitting organisms. The starch iodide test was made on the water used for reconditioning to ascertain at what point all of the excess chlorine had been washed out of the mineral.

(C) *Results*

1. Laboratory tests. Since the quality of drinking water is largely judged on the basis of the presence or absence of Bacterium coli, it was thought best to employ for the laboratory experiments a water which was known to contain this organism. Raw infiltration gallery water from the Iowa City water plant, therefore, was used. This water was passed through the laboratory filters, the experiments on sand serving as a check upon the zeolitic filters.

The water was passed through the filters at a rate of 250 cc. in fifteen minutes, a rate comparable to the ordinary softening rate for these materials. Samples were taken for analysis from each 250 cc. passed. The results are given in tables 1 and 2.

At the time that the bacteriological tests were being run, determinations were made on the removal of turbid matter from the raw water being passed through the filters. The turbidities remaining are recorded in table 3.

A physical analysis of the minerals used was made. The uniformity coefficient and the effective size was determined according

TABLE 1

Removal of bacteria by zeolitic water softeners—Test 1. Laboratory filters

SAMPLES	COLONIES PER CUBIC CENTIMETER			FERMENTATION TESTS			
				Lactose broth—37°C			
	Plain agar 20°C.—48 hours	Litmus lactose agar 37°C.—24 hours.	Acid colonies.	24 hours		48 hours	
				10 cc.	1 cc.	10 cc.	1 cc.
Raw river	5000–6000	6000–10000	0–0	1/1	2/2	1/1	2/2
Refinite, 1st 250 cc	5000–6000	3000– 2500	0–0	1/1	1/2	1/1	2/2
Refinite, 2nd 250 cc	2000–1500	3000– 2500	0–0	1/1	2/2	1/1	2/2
Refinite, 3rd 250 cc	2800–3000	3200– 3000	0–0	1/1	2/2	1/1	2/2
Permutit, 1st 250 cc	3000–3000	2100– 2200	0–0	1/1	1/2	1/1	2/2
Permutit, 2nd 250 cc	4000–3500	3000– 2950	0–0	1/1	2/2	1/1	2/2
Permutit, 3rd 250 cc	2300–2800	3200– 3000	0–0	1/1	2/2	1/1	2/2
Borromite 1st 250 cc	2000–2500	2400– 2000	0–0	1/1	2/2	1/1	2/2
Borromite, 2nd 250 cc	3000–2000	3500– 3100	0–0	1/1	2/2	1/1	2/2
Borromite, 3rd 250 cc	2100–3000	3200– 3000	0–0	1/1	2/2	1/1	2/2
Sand, 1st 250 cc	4100–6000	5000– 8000	0–0	1/1	2/2	1/1	2/2
Sand, 2nd 250 cc	4000–5000	750– 900	0–0	1/1	2/2	1/1	2/2
Sand, 3rd 250 cc	4000–2000	2200– 2000	0–0	1/1	2/2	1/1	2/2

Note: All gas formation was confirmed on eosin methylene blue plates and in every case gave positive tests for B. coli.

TABLE 2

Removal of bacteria by zeolitic water softeners—Test 2. Laboratory filters

SAMPLES	COLONIES PER CUBIC CENTIMETER			FERMENTATION TESTS			
				Lactose broth—37°C.			
	Plain agar 20°C.—48 hours.	Litmus lactose agar 37°C.—24 hours	Acid colonies	24 hours		48 hour	
				10 cc.	1 cc.	10 cc.	1 cc.
Raw river	7500–8000	2000–2500	0–0	1/1	2/2	1/1	2/2
Refinite, 1st 250 cc	5000–7000	500– 450	0–0	1/1	2/2	1/1	2/2
Refinite, 2nd 250 cc	4500–4500	750– 800	0–0	1/1	2/2	1/1	2/2
Refinite, 3rd 250 cc	5000–4500	500– 500	0–0	1/1	2/2	1/1	2/2
Permutit, 1st 250 cc	2500–3500	500– 600	0–0	1/1	2/2	1/1	2/2
Permutit, 2nd 250 cc	1900–1800	600– 600	0–0	1/1	2/2	1/1	2/2
Permutit, 3rd 250 cc	2750–2600	850– 700	0–0	1/1	2/2	1/1	2/2
Borromite, 1st 250 cc	3000–2750	400– 400	0–0	1/1	2/2	1/1	2/2
Borromite, 2nd 250 cc	3000–1200	250– 400	0–0	1/1	2/2	1/1	2/2
Borromite, 3rd 250 cc	2000–2000	350– 400	0–0	1/1	2/2	1/1	2/2
Sand, 1st 250 cc	3500–2500	400– 400	0–0	1/1	2/2	1/1	2/2
Sand, 2nd 250 cc	2500–2000	350– 230	0–0	1/1	2/2	1/1	2/2
Sand, 3rd 250 cc	1800–2900	400– 250	0–0	1/1	1/2	1/1	2/2

Note: All gas formation was confirmed on eosin methylene blue plates, and in every case gave positive tests for B. coli.

to the method given by Flinn, Weston and Bogert (4). The results of the tests are given in table 4.

2. Tests upon domestic and industrial installations. Samples were collected periodically for analysis from the units already described. The results are recorded in tables 5, 6, 7, 8, 9 and 10, and represent the conditions of normal operation of the domestic softeners and the commercial permutit installation.

TABLE 3

Reduction of turbidity on filtration of water through zeolites

	TURBIDITIES IN PARTS PER MILLION					
	250 cc. water passed, Test 1			250 cc. water passed, Test 2		
	First	Second	Third	First	Second	Third
Raw water	400			290		
Refinite	420	170	160	180	120	130
Permutit	190	125	110	100	100	100
Borromite	110	80	40	110	50	40
Sand	60	50	30	20	15	10

TABLE 4

Physical analysis of zeolite samples

	UNIFORMITY COEFFICIENT	EFFECTIVE SIZE
		mm.
Refinite	1.55	0.524
Permutit	1.89	0.380
Borromite	1.54	0.221
Sand	1.76	0.261

Since the domestic units were operated only intermittently, they represent a condition similar to that of any household softener. Before samples were collected for analysis the water was allowed to flow through the filters for five minutes. The samples on April 27, 1921, were collected after the softeners had stood idle for some time. They were then reconditioned and the samples on April 29 were collected immediately after zero hardness water was obtained from each softener. Additional samples were taken for analysis on May 2. The tests on June 2 were made immediately after reconditioning. Additional tests were made on June 6 and 7, before the capacities of the softeners had been exhausted.

TABLE 5

Analysis of samples collected April 27, 1921

SAMPLES	COLONIES PER CUBIC CENTIMETER			FERMENTATION TESTS	
	Plain agar 20°C.—48 hours	Litmus lactose agar 37°C.—24 hours	Acid colonies	Lactose broth 37°C.	
				24 hours 10 cc.	48 hours 10 cc.
Raw water, N. P. Laundry.....	9–7	6–8	0–0	0/5	3/5
Filtered water, N. P. Laundry ..	980–850	152–144	0–0	0/5	1/5
Raw water, Close Hall.....	1–7	4000–5000	0–0	0/5	4/5
Refinite filtered water, Close Hall.....	500–800	5000–6500	0–0	0/5	4/5
Permutit filtered water, Close Hall.....	200–230	1270–1210	0–1	0/5	5/5
Borromite filtered water, Close Hall.....	800–600	6000–5400	0–0	0/5	5/5

Note: None of the gas formers confirmed for B. coli when transferred to eosin methylene blue plates.

All the samples from the New Process Laundry were collected in the afternoons, after reconditioning of the system in the morning of the days on which the samples were collected.

TABLE 6

Analysis of samples collected April 29, 1921

SAMPLES	COLONIES PER CUBIC CENTIMETER			FERMENTATION TESTS	
	Plain agar 20°C.—48 hours	Litmus lactose agar 37°C.—24 hours	Acid colonies	Lactose broth 37°C.	
				24 hours 10 cc.	48 hours 10 cc.
Raw water, N. P. Laundry.....	6–5	5–3	0–0	0/5	0/5
Filtered water, N. P. Laundry..	600–500	200–220	0–1	0/5	0/5
Raw water, Close Hall.....	3–2	5000–4000	0–0	0/5	0/5
Refinite filtered water, Close Hall.....	350–240	1200–800	0–4	0/5	0/5
Permutit filtered water, Close Hall.....	220–260	100–270	0–0	0/5	0/5
Borromite filtered water, Close Hall.....	6–1	500–680	0–0	0/5	0/5

TABLE 7

Analysis of samples collected May 2, 1921

SAMPLES	COLONIES PER CUBIC CENTIMETER			FERMENTATION TESTS	
	Plain agar 20°C.—48 hours	Litmus lactose agar 37°C.—24 hours	Acid colonies	Lactose broth 37°C.	
				24 hours 10 cc.	48 hours 10 cc.
Raw water, N. P. Laundry.....	7–10	8–21	0–0	0/5	0/5
Filtered water, N. P. Laundry..	200–250	120–140	0–0	0/5	0/5
Raw water, Close Hall.....	3–5	4000–5000	0–0	0/5	0/5
Refinite filtered water, Close Hall.....	300–200	500–600	0–2	1/5	1/5
Permutit filtered water, Close Hall.....	120–130	90–110	0–0	0/5	0/5
Borromite filtered water, Close Hall.....	2–3	200–300	0–0	0/5	0/5

Note: The gas produced in the Refinite filtered water did not confirm for B. coli.

3. Sterilization experiments. Varying amounts of sodium hypochlorite were placed in the borromite softeners at the same time the salt was introduced for reconditioning the units. The sodium

TABLE 8

Analysis of samples collected June 2, 1921

SAMPLES	COLONIES PER CUBIC CENTIMETER			FERMENTATION TESTS			
	Plain agar 20°C.—48 hours	Litmus lactose agar 37°C.—48 hours	Acid colonies	Lactose broth 37°C.			
				24 hours		48 hours	
				10 cc.	1 cc.	10 cc.	1 cc.
Raw water, N. P. Laundry	420–290	190–120	0–0	0/1	0/2	1/1	0/2
Filtered water, N. P. Laundry.....	1000–600	2100–1800	0–0	0/1	0/2	0/1	0/2
Raw water, Close Hall.....	140–260	260–250	0–0	0/1	0/2	1/1	2/2
Refinite filtered water, Close Hall.....	100–150	200–350	0–0	0/1	0/2	0/1	0/2
Permutit filtered water, Close Hall.....	160–200	250–225	0–0	0/1	0/2	1/1	0/2
Borromite filtered water, Close Hall.....	200–200	300–500	0–0	0/1	0/2	1/1	0/2

Note: Gas production in the 10 cc. tubes of the raw water, Close Hall and that passing the permutit and borromite filters, when confirmed, gave positive tests for B. coli.

TABLE 9

Analysis of samples collected June 6, 1921

SAMPLES	COLONIES PER CUBIC CENTIMETER			FERMENTATION TESTS			
				Lactose broth 37°C.			
				24 hours		48 hours	
	Plain agar 20°C.—48 hours	Litmus lactose agar 27°C.—24 hours	Acid colonies	10 cc.	1 cc.	10 cc.	1 cc.
Raw water, N. P. Laundry	120–160	100–87	0–0	0/1	0/2	0/1	0/2
Filtered water, N. P. Laundry	340–220	600–750	0–0	0/1	0/2	0/1	0/2
Raw water, Close Hall	8–10	200–225	0–0	0/1	0/2	0/1	2/2
Refinite filtered water, Close Hall	190–180	280–260	0–0	0/1	0/2	0/1	0/2
Permutit filtered water, Close Hall	150–160	250–240	0–0	0/1	0/2	0/1	1/2
Borromite filtered water, Close Hall	150–190	200–210	0–0	0/1	0/2	0/1	0/2

Note: Confirmation test showed absence of B. coli in the 1 cc. permutit passed sample.

hypochlorite used contained an available chlorine content of 2 per cent. Immediately after the introduction of the salt and the hypochlorite, the washing of the unit was started. In all tests, as shown

TABLE 10

Analysis of samples collected June 7, 1921

SAMPLES	COLONIES PER CUBIC CENTIMETER			FERMENTATION TESTS			
				Lactose broth 37°C.			
				24 hours		48 hours	
	Plain agar 20°C.—48 hours	Litmus lactose agar 37°.C—24 hours	Acid colonies	10 cc.	1 cc.	10 cc.	1 cc.
Raw water, N. P. Laundry	7–8	6–5	0–0	0/1	0/2	0/1	0/2
Filtered water, N. P. Laundry	24–55	100–120	0–0	0/1	0/2	0/1	0/2
Raw water, Close Hall	10–15	160–180	0–0	0/1	0/2	0/1	0/2
Refinite filtered water, Close Hall	220–250	310–310	0–0	0/1	0/2	0/1	0/2
Permutit filtered water, Close Hall	140–150	87–75	0–0	0/1	0/2	0/1	0/2
Borromite filtered water, Close Hall	52–48	120–170	0–0	0/1	0/2	0/1	0/2

by the starch iodide test, the excess chlorine was completely washed out before soft water was obtained. Continuous softening experiments were made and samples were collected at intervals for analysis.

The results are given in tables 11, 12, 13, and 14.

TABLE 11

Sterilization with 100 cc. and 200 cc. sodium hypochlorite

SOURCE OF SAMPLE	COLONIES PER CUBIC CENTIMETER OF WATER					
			Softener no. 1 100 cc. sodium hypochlorite		Softener no. 2 200 cc. sodium hypochlorite	
	24 hours	48 hours	24 hours	48 hours	24 hours	48 hours
Raw water	70	300				
End of salting			10	150	0	4
End of 300 gallons			70	170	26	64
End of 800 gallons			70	192	70	140

TABLE 12

Sterilization with 50 cc. sodium hypochlorite

SOURCE OF SAMPLE	COLONIES PER CUBIC CENTIMETER OF WATER					
			Softener no. 1		Softener no. 2	
	24 hours	48 hours	24 hours	48 hours	24 hours	48 hours
Raw water	15	69				
End of salting			5	23	23	54
End 300 gallons			No test		No test	
End 800 gallons			34	71	22	63

TABLE 13

Sterilization with 25 cc. sodium hypochlorite

SOURCE OF SAMPLE	COLONIES PER CUBIC CENTIMETER IN WATER					
			Softener no. 1		Softener no. 2	
	24 hours	48 hours	24 hours	48 hours	24 hours	48 hours
Raw water	16	Spreader				
During salting—still a test for Cl.			2	2	2	2
End of 300 gallons			No test		No test	
End of 800 gallons			96	140	77	130

At the end of these tests an experiment was made on the softeners to determine the minimum amount of sodium hypochlorite that could be used and still obtain a starch iodide test through the softeners. Ten cubic centimeters and 15 cc. gave strong tests, while 5cc. gave only a very faint test.

Softening experiments which were run along with the sterilization experiments showed that the softening power of the borromite was not apparently affected by the hypochlorite treatment.

TABLE 14

Sterilization with 20 cc. sodium hypochlorite

SOURCE OF SAMPLE	COLONIES PER CUBIC CENTIMETER OF WATER					
			Softener no. 1		Softener no. 2	
	24 hours	48 hours	24 hours	48 hours	24 hours	48 hours
Raw water	5	62				
During salting—still a test for Cl			2	2	2	27
End of salting			44	210	16	150
End of 500 gallons			103	225	91	240
End of 800 gallons			61	310	39	250

III. DISCUSSION OF RESULTS AND THEORETICAL CONSIDERATIONS

It is evident that the common zeolitic water softeners do not produce a sterilizing action. Newly prepared permutit may possess a sterilizing action due to its strongly alkaline reaction, but if it has this property it disappears with use. It is true, when a highly contaminated water is filtered through the zeolites, there is a material reduction in the number of bacteria. They do not, however, possess this property to any greater extent than does sand. It would seem, therefore, that their action must be largely a mechanical one, not due to any *special* adsorptive powers of the zeolites. It is not difficult to understand why refinite and permutit, although much coarser in texture than the sand and borromite should give almost as good bacterial removal. It is a well known fact that a sand filter does not effectively remove bacteria until a schmutzdecke is formed, and the bacterial removal is largely in this covering. During the course of the laboratory experiments, the formation of an effective covering of this sort was impossible. Due to the coarser texture (table 4)

of refinite and permutit, its formation would be greatly retarded while it should form as well on borromite as on sand. It is probable that if the experiments had been extended that far, more efficient bacterial removal would have resulted. In actual operating conditions, however, zeolitic water softeners do not form a very heavy *schmutzdecke*. A clear water must be used, for if it is not, the grains become coated and the softening properties are greatly impaired. Hence, the experiments were not carried to that point. The laboratory experiments show conclusively that B. coli is not quantitatively removed.

As shown by the tests upon the New Process Laundry permutit installation and the domestic softeners previously described, it is evident that the bacterial counts may, and in most cases where a water of low bacterial content is used do, increase upon filtration. This may be due to several causes, one of which is evidently the external pollution brought about during reconditioning. During operation the filters collect considerable slime, particularly if a perfectly clear water is not being used and if the filter is not thoroughly backwashed preceding the reconditioning. This material offers an excellent medium for bacterial multiplication. Where softeners stand idle for some time bad odors often result, due to anaerobic bacterial action and the bacterial count may increase to an extremely large number. The importance of a thorough backwash cannot be too strongly emphasized, as it is essential, not only for minimizing the bacterial multiplication, but also for the best softening conditions. It is possible, though not highly probable, that some bacteria may be absorbed along with the hardening salts and it is difficult to remove them with a vigorous backwash.

Although the bacterial counts on the filtered water may increase over that of the raw water with a small number of organisms, there may be no other indications that the water is not suitable for drinking. The absence of all gas formers, in all cases where they were absent in the raw water, is important.

It is frequently remarked that zeolitic-softened waters have a "flat" taste. This is quite true, but the objection to the flat taste usually disappears as one becomes accustomed to the water. In spite of the entire absence of hardening salts, which have been removed by the zeolites, the water after carbonating is free from the objectionable flat taste. Such softened waters should be suitable

for bottled drinks, if sterilized previous to use, since all the objectionable salts have been removed. In many cases the troubles which render bottled drinks unmerchantable are due to fermentation of the sugars employed in the flavoring syrups. The fermentation may be due to bacteria or to yeasts.

It is claimed that people suffering from gall stones may get relief by drinking zeolitic softened waters, but the author cannot vouch for the truth of the statement.

IV. CONCLUSIONS

Zeolitic water-softening filters materially reduce the bacterial content of highly contaminated waters, but do not quantitatively remove Bacterium coli. If such a water is to be used for drinking purposes the filtration should be followed by chlorine treatment.

Although a water initially of low bacterial count may increase in bacterial content upon passage through zeolitic filters, there is no evidence for deciding that such a water is unsuitable for drinking purposes, if the raw water is safe. As a factor of safety it may be desirable occasionally to sterilize the filters with sodium hypochlorite or bleaching powder. Liquid chlorine might be used in commercial plants.

Bacterial removal by zeolitic filters is a mechanical phenomenon and is not dependent upon any sterilizing action of the minerals.

A high rate of backwash is desirable for the removal of bacteria from the softeners. If the softeners stand idle for some time they should be opened to allow access of air to prevent anaerobic decomposition of the organic material collected in the filter. They should then be thoroughly backwashed before being put into service again.

Zeolitic softened waters should be suitable for bottled drinks if sterile conditions are maintained. If sugar-splitting organisms are absent in the raw water, zeolitic softened water should be satisfactory for bottled drinks even without sterilization. The use of a stone filter might be advisable after a zeolitic softener to help reduce organic growths in the finished goods.

Of the common zeolitic water softeners borromite seems to possess a somewhat greater ability to remove bacteria. Because of its physical structure and density, it offers the possibility of acting both as a filtering and as a softening medium.

REFERENCES

1. Thos. R. Duggan, Commercial application of artificial zeolites. Orig. Com. 8th Intern. Congr. Appl. Chem. (Appendix), **25,** 125–9; Chem. Abstracts, **7,** 2267.
2. Albert Bencke. The present status of the permutit process for the purification and softening of service and drinking waters. Gesund. Ing. 36, 282–4; Chemical Abstracts **7,** 2268.
3. Anon. German Water Softener, Permutit. Weekly Consular Trade Reports 4, 178; Chemical Abstracts, **4,** 1519.
4. Flinn, Weston and Bogert. Waterworks Handbook, pp. 739–41, New York, 1916.

TURBIDIMETRY OF WATER[1]

By P. V. Wells[2]

The famous experiment of Tyndall, which explained the blue color of the sky, was to focus in a narrow pencil the extremely powerful light from an electric arc, and to examine the "Tyndall beam" from the side, against a dark background. The young Lord Rayleigh has recently measured in this manner the light scattered by gas molecules themselves. Such light is of a saturated blue color and the theory of the late Lord Rayleigh indicates that its intensity (I) increases with the size of particle according to the relation

$$\frac{I}{I_0} = k\frac{C\,x\,d^3}{\lambda^4} \quad (d << \lambda) \tag{1}$$

where (I_o) is the original intensity, (C) the concentration of the particles of diameter (d), (x) the depth of beam and (λ) the wave length of the scattered light.

This formula holds only for particles vanishingly small compared with the wave length of light. But water analysts are concerned mainly with coarser suspensions, the muddy appearance of which is due not to scattered light but to reflected light. The intensity of light reflected by coarse particles increases in proportion to their total surface, so that

$$\frac{I}{I_0} = k\frac{C\,x}{d} \quad (d >> \lambda) \tag{2}$$

This agrees with the experimental fact that smaller particles give higher turbidities in ordinary suspensions.

The transition from diffuse reflection to scattering occurs in the region of the wave length of light. Mie finds this to occur at ($d = \lambda/3$ to $\lambda/4$) which is just about the limit of resolution of par-

[1] Read before the Chemical and Bacteriological Section, at the Cleveland Convention, June 9, 1921.

[2] Associate Physicist, Bureau of Standards, Washington, D. C.

ticles in the microscope. Hence we may combine equations (1) and (2) in a single formula,

$$\frac{I}{I_0} = k \frac{C x d^3}{d^4 + 0.002\lambda^4} \tag{3}$$

Instruments which measure the intensity of the Tyndall beam are usually called *tyndallmeters*, and are most sensitive for very small turbidities. Thus Richards' nephelometer is a comparison form of tyndallmeter.

For over a hundred years the oceanographer has lowered circular discs of canvas into the sea to measure the transparency of sea water, and the turbidity standard of water analysis does not differ in principle from this method. The theory of the disappearance criterion is very complicated, but as an empirical method it is remarkably simple, free from disturbing factors, and reproducible. Instruments based upon the disappearance method are usually called *turbidimeters*.

Turbidity is expressed as a concentration (parts per million, or milligrams per liter), but the concentration cannot be measured directly, either by a tyndallmeter or by a turbidimeter. In fact both these instruments measure a complicated function of the concentration, the size of particles, and density constants of the dispersed and continuous phases, to say nothing of secondary factors. A single observation, such as turbidity or tyndall-intensity, cannot be expected to specify with any completeness a complicated and variable suspension or any other type of dispersoid.

In order to gain some impression of the complicated nature of a dispersoid, consider a standard silica suspension of 100 parts per million (10^{-4} = 100 milligrams per liter). Suppose this suspension to be composed of spheres of perfectly pure silica dispersed in pure water, and of uniform diameter 1 micron = 10^{-4} cm. In order to produce this concentration about 10^8 = 100,000,000 particles per cubic centimeter are required, and although these particles occupy less than one-thirty-thousandth of the volume, they present a surface of over one square centimeter per cubic centimeter. They are on the average about 2×10^{-3} cm. = 20 microns apart, and diffuse this distance in about eight minutes, because of the incessant Brownian agitation. Carried about by convection currents and by diffusion, the particles are continually coalescing to form larger aggregates, unless some force such as electrostatic repulsion keeps

them separated. Hence the suspension, initially uniform, soon contains larger particles which settle out more rapidly. But in practise the particles are distributed in size and are further covered with adsorbed layers of various impurities, etc., presenting an extremely complicated system. These complications seriously retard progress in the systematic study of dispersoids.

One of the simplest means of specifying the size distribution of the particles forming the dispersed phase in the "settling curve." A tyndallmeter is quite appropriate for this purpose, the tyndall-intensity being read at equal logarithmic intervals of time. It possesses the advantage of sensitiveness over the Odén balance method. Changes in tyndall-intensity corresponding to the settling out of masses quite beyond the possibility of weighing are easily measured. Moreover the sample can be enclosed and evaporation prevented, and the effect of humidity in changing the apparent weight does not enter as a disturbing factor. But the interpretation of the observed quantity (tyndall-intensity) is not so direct as that of the balance method (total mass settled out). The possibilities of the method are now being tested.

THE PHYSICAL CHEMISTRY OF DEFERRIZATION[1]

By Robert Spurr Weston[2]

In the course of human progress, it becomes necessary from time to time to re-state ideas in terms of the day. This necessity is not confined to science and technology, but is the rule where mankind progresses. Even so universal a human element as religion requires for its expression frequent "new bottles" for its "old wine." So, today, we are forced to use new terms to explain the deferrization process and are hopeful that the physical chemist and his colloidal brother will throw new light upon some of the reactions and interferences, now in obscurity. In what follows, the writer will try to restate his own conceptions of the deferrization process in physico-chemical language.

While deferrization (and demanganization) is as old as the spring-fed bogs from which organisms and oxygen caused the deposition of iron and the ultimate formation of iron ore, the deferrization process for water is barely a half-century old. Even in such a comprehensive book as William Ripley Nichols' "Water Supply," published in 1883, there is practically no recognition of it and until within a few years the process was applied only to waters from which the iron was removed with great ease, i.e., waters of high pH value, high in bicarbonates and low in "potent" carbon dioxide. Most of these cases were in Europe. In the United States, the process was first applied along the New Jersey shore where conditions were favorable.

In the eighteen-nineties, there occurred cases like Superior, Wisconsin, and Reading, Mass., where the explanation of the results obtained is not found in the reaction formulae, viz.,

A. *Iron as carbonate*

$$2\,FeCO_3 + 2\,CO_2 + 2\,H_2O + 2\,O = 2\,Fe(OH)_2 + O\ (+CO_2)$$

$$2\,Fe(OH)_2 + O + H_2O = Fe_2(OH)_6$$

B. *Iron as sulfate*

$$FeSO_4 + CaCO_3 = FeCO_3 + CaSO_4$$

$FeCO_3$ as in A.

---

[1] Read before the Chemical and Bacteriological Section, at the Cleveland Convention, June 9, 1921.

[2] Of Weston & Sampson, Consulting Engineers, 14 Beacon St., Boston.

In one case, good results could be obtained only by limiting the degree of aeration, and in the other by vigorous treatment with lime and sulfate of alumina.

The writer's first conceptions of the process were that iron exists in water as carbonate or sulfate with carbon dioxide or hydrogen sulfide as a solvent. Aeration was necessary to drive off the solvent gases and oxidize the soluble iron to insoluble hydrated oxide, setting free acid in the process. There was little thought of disturbed equilibrium, speed of reaction, electric charges of particles, interfering gels and emulsoids, or the bearing of the hydrogen ion concentration. Even at this writing, our thoughts are fluent. We can neither let the old idols fall, nor place our entire faith in the new and untried.

We now believe that iron in the waters of springs or wells is partly in the form of a salt, partly in the form of a sol of ferrous hydrate, or again in the form of a suspension of compounds of iron with organic matter. When the proportion of solvent—carbonic and other acids—is high and oxygen is absent, the percentage of hydrate sol is negligible or absent.

The steps in the deferrization process are: (1) Aeration and removal of acid; (2) hydrolysis; (3) coagulation.

AERATION AND REMOVAL OF ACID

The absorption of enough oxygen to oxidize the ferrous iron to ferric iron is a simple matter—1 part of oxygen will oxidize 8 parts of iron—but aeration also serves to reduce the carbonic acid to a point where rapid hydrolysis takes place and in the majority of cases should proceed until an equilibrium can be established between ferric hydrate, later removed by coagulation and filtration, and the oxygen on the one hand, and the solvent carbonic and other acids, on the other.

In certain cases, aeration may be carried so far as to upset the relations between part of the iron and the organic matter wherein the presence of a certain amount of carbonic acid seems necessary to prevent the effect of iron upon organic matter. The iron is perhaps in the form of a hydrate sol, protected by a very stable organic sol which latter is neutralized in effect by the presence of carbonic acid.

Much less acid is required to prevent precipitation of manganese than of iron, and in one case it was possible to completely remove the iron and leave the manganese in practically permanent solution simply by stopping the aeration at the proper point.

HYDROLYSIS

Ferrous hydrate is converted to ferric hydrate by hydrolysis, i.e., by the action of water and oxygen; $2Fe(OH)_2 + 2H_2O + O = 2Fe(OH)_3 + H_2O$, the OH of the water combining with the hydrate and the hydrogen combining with the O to form water.

Goodwin states that this is a time reaction, and as it is one of adding OH, the presence of hydrates increases its speed. This is why lime and caustic soda are efficient accelerating agents in deferrization, and why more than enough oxygen is of so little importance. Contrarily, the presence of acids retards hydrolysis.

Hydrolysis is promoted by contact with ferric hydrate already formed and precipitated. Dunbar and Kryck proved that the absorption of oxygen during hydrolysis was much more rapid in a coke filter which had accumulated a considerable bulk of hydrate. The use in our own practice of coke towers of various heights is for this purpose as well as for coagulation. It must be remembered that ferric hydrate is a very weak base, but insoluble, consequently the equilibrium point is very far toward the hydrate side of the equation.

A difficult problem is the hydrolysis of ferrous sulfate, the product being sulfuric acid which, when carbonates are present, reacts to set free carbon dioxide which may reverse the reaction and throw the equilibrium point towards the sulfate side. The obvious remedy is the presence of a hydrate, or aeration prolonged until complete hydrolysis is secured. Sulfates, however, tend to precipitate the ferric hydrate from its sol.

COAGULATION

When hydrolysis is complete, the ferric hydrate exists as a ferric hydrate sol, or colloidal suspension from which the fine particles must be precipitated by gathering them into aggregates large enough to be precipitated by gravity or be caught in the sand layer of a filter.

In pure water, this hydrate would be instantly precipitated from its sol by electrolytes. But natural water contains electrolytes, yet the precipitation of iron is often very difficult. The valency of the electrolyte is an important factor, the sulfates and other bivalent anions being much more potent than chlorine and other univalent anions. For this reason, hard waters usually part with their iron with ease.

Important in this connection are the effects of agitation, friction and contact, and in these respects the phenomena are so similar to those incident to the coagulation of waters with aluminum hydrate that it is hardly worth while to discuss them in detail. Suffice it to say that with some waters, prolonged contact will often allow one to avoid the addition of chemicals.

The effect of temperature is to increase the speed of all the reactions. On the other hand, the rate of absorption of oxygen and gas exchange is decreased.

A type of water hard to purify is the one containing a small amount of iron, say less than 1 p.p.m., and a relatively large amount of peaty organic matter. Here the organic matter seems to act as a protecting colloid and prevents coagulation just as if gelatine, albumen or another emulsoid were present.

Clark showed that such waters could be purified by overloading the positive side of the system, i.e., the iron hydrate, by introducing metallic iron. Obviously aluminum hydrate would have the same effect, although sulfate of alumina, because of its reaction products, which are acid, is not always a successful accelerant.

It is now generally believed that colloidal ferric hydrate, in its dispersed phase, is so maintained by the electric charges of the particles which are positive. If so, the most favorable condition for precipitation is the neutralization of the positive charge due to the absorption of kations by the absorption of anions having negative charges. Thus we find that the precipitating power of an electrolyte depends upon the valency of the ion whose electric charge is negative. Thus, sulfates are more effective than chlorides. Similarly soft ferruginous waters are more difficult to treat than hard.

The natural precipitation of colloids is an interesting phenomenon of deferrization. In 1907, it was found at Posen (Poland) that the colloidal iron in the water from deep wells could be precipitated if mixed in proper proportions with the colored shallow well water containing a colloidal suspension of iron combined with organic matter having negatively charged particles. In this case, precipitation took place when the charges of the particles were neutralized. An excess of either water prevented precipitation, but there existed a zone of precipitation in a series of mixtures of the two waters in ascending and descending amounts respectively. After seeing this interesting experiment, the writer was able to reproduce it using a dark-brown, deep well water from New Orleans, and a clear shallow well water from Massachusetts.

While the presence, side by side, of two waters containing mutually precipitating colloids is not to be met in our practice, it suggests the use of other negative colloids, silica, for example, as reagents for the precipitation of iron. It is only by studies along physico-chemical lines that the deferrization of difficult waters by means other than by vigorous treatment with chemicals may be effected and it is believed that the determination of the hydrogen ion concentration of waters at different stages in the deferrization process will enable us to control it more effectively than at present.

COAGULATION AND SEDIMENTATION WITH CHEMICALS[1]

By J. W. Ellms[2]

Coagulation and sedimentation with chemicals, followed by rapid filtration through sand filters, have become the generally adopted methods of purifying the public water supplies in the United States. Even where the softening of a water supply comprises the principal portion of the process, coagulation, sedimentation and filtration are important factors in the final cleansing of the water. The method of applying the chemicals and the effects they produce are, therefore, of the greatest significance.

If the phenomena accompanying the processes of coagulation and sedimentation are carefully studied, it soon becomes evident that we are dealing with chemical reactions on a large scale, and that the physical changes brought about by these reactions are governed by principles and laws which have been investigated by scientists within comparatively recent years, and classified by them under the names of physical and colloidal chemistry. The phenomena are complex and by no means entirely understood in all of their ramifications. The object of the present paper is to outline and classify the various factors entering into the processes of water purification without going too deeply into details. The practical value of understanding the main features of these processes, in relation to the design of the structures in which they occur, is obvious, and at least may justify the effort to set forth in an orderly manner the changes that take place.

Excluding for the time being those phases of the problem which relate to water softening, let us consider those which have to do with purification by clarification, that is, with the removal of suspended impurities. In natural waters used for public supplies, there are usually found both inorganic and organic matter which are not in

[1] Presented before the Chemical and Bacteriological Section at the Cleveland Convention, June 9, 1921.

[2] The Frazier-Ellms-Sheal Company, Consulting Engineers, Cleveland, Ohio.

solution, but which are in an extremely finely divided state. Some of this material does not readily settle out, even when the water is quiescent. Some of the organic matter appears to be in actual solution, although it has been discovered that this is not always the case. Such material will not precipitate unless the size of the particles of which it is composed is enlarged, or is trapped by other material which is collecting into larger masses and thus becomes capable of being deposited by sedimentation.

The impurities referred to in the above paragraph consist chiefly of inorganic compounds or mixtures commonly known as clay and silt, and of organic matter, both dead and living. In the dead organic matter may be found nitrogenous and carbonaceous compounds, and in the living matter, bacteria and microscopic plant and animal forms. Much of the inorganic material is in that finely divided condition known as the colloidal state of matter. The dead organic matter is usually in this condition, while the cells of the living organic matter may be always considered as in this form.

Since a portion of the suspended impurities are, on account of their extraordinarily small size, not capable of settling out unaided, it becomes necessary to add something to the water which will cause these particles to come together. The aggregation of these particles into masses of such size that they may settle out is commonly known as coagulation. This process is usually effected through the agency of a chemical compound such as aluminum sulphate or ferrous sulphate, which, in reacting with the natural alkalinity of the water or with an alkalinity created by the addition of lime or soda ash, produces a colloidal precipitate. The latter by reason of the electrical charges upon its particles, which are of opposite sign from those on most of the natural colloidal impurities, brings about coagulation of the suspended matter, and subsequently is settled out under proper conditions.

From the above it is evident that there first occurs one or more chemical reactions followed by certain physical changes. It is this actual division of the process into two parts to which attention should be directed, if the full significance of the phenomena involved is to be understood. The reaction between the sulphate of aluminum and the alkali in the water is the usual exchange of ions, whereby an insoluble or practically insoluble product is one of the results of the reaction. Every precipitation is preceded by a state of supersaturation with respect to the precipitated solid, and after it is complete, the liquid

is saturated with it, i.e., it is in equilibrium with the liquid. The establishing of this equilibrium may require considerable time, and depends entirely upon the properties of the compound resulting from the chemical reaction, and from the physical and chemical characteristics of the water in which the reaction takes place.

It is necessary, therefore, to realize that a chemical reaction or series of reactions precedes changes which establish physical equilibrium. The velocity of most chemical reactions, at least of those commonly met with in water purification, is extremely high, in fact too high to be able properly to measure the time in which they occur. The higher the temperature, the more rapid are the ionic exchanges. If more than one reaction is necessary, as in the case of ferrous sulphate and lime, or lime and soda ash in water softening, probably a somewhat longer time is needed, but even here the chemical reactions practically complete themselves in an immeasurably short space of time.

The foregoing statement is true only if the reacting substances are in solution. The velocity of a reaction is directly proportional to the concentration of each reacting constituent, and is understood to be the ratio between the amounts of the transformed substances and the time required for transforming them. The greatest velocity-value is at the beginning of the reaction, and becomes less and less as the reaction proceeds, and leads to the theoretical result that the reaction is only complete after an infinite length of time. But while this may be absolutely true, for practical purposes any residual action may be regarded as non-measureable after ten times the period which is required to complete the first half of the reaction.[3] Since for homogeneous mixtures of reacting solutions of the general character used in coagulating a water, the velocity of the reaction at the start is very high, it follows that the reacting quantities in the residual action are practically negligible. However, in non-homogeneous mixtures, such as occur when feeding milk of lime, or dry feeding of hydrated lime, aluminum sulphate or even sulphate of iron, true solution of these reagents must precede reaction, and hence the actual or practical completion of the reaction may take a sensible period of time.

The second part of the phenomena, that is, the adjustment of the solid phases of the products of the reaction to the liquid, requires

[3] Foundations of Analytical Chemistry, Wm. Ostwald.

more or less time. As all precipitates are probably at first in a colloidal form, as previously stated, and as the speed with which they pass through this stage depends upon several factors which differ with the different chemicals employed, it is evident that each case will require more or less special consideration.

When aluminum hydroxide is one of the reaction products, there are comparatively few complications. It is a relatively insoluble compound, and the carbon dioxide formed at the same time appears to have no inhibiting effect. Slow coagulation, therefore, may be due to protective colloids naturally present in the water, to lack of negatively charged colloidal particles to neutralize the positively charged particles of aluminum hydroxide, to very low temperatures, or to insufficient movement of the water to facilitate contact of suspended particles.

In the case of ferrous sulphate, its decomposition first produces ferrous bicarbonate, which, because of its instability and because of the lime always added with the iron sulphate, is quickly converted into ferrous hydroxide and calcium carbonate. The oxygen dissolved in the water rapidly oxidizes the ferrous iron to the ferric condition, and there is finally produced ferric hydroxide, or the coagulating compound desired. Here there are a series of reactions followed by the usual phenomena of matter in the colloidal condition.

In the softening of water with lime and soda ash, the ionic exchanges between the CO_3, HCO_3, SO_4, Ca and Mg ions constitute a series of chemical reactions intermingled with physical changes, which require more or less time for their completion. Calcium carbonate comes down first in an amorphous form, and in this state is perceptibly soluble in the water. The amorphous form gradually changes to the crystalline (assuming the rhombohedral forms of calc spar) which is much more insoluble in the water. Magnesium carbonate is very soluble in water, and even the hydroxide is relatively soluble unless an increased concentration of hydroxyl ions, produced by adding an excess of alkali (CaO_2H_2 or NaOH), decreases its solubility sufficiently to cause most of it to settle out.

In water softening considerable masses of deposited sludge are usually in contact with the water during the purification process. Since equilibrium must be established between the water (which is supersaturated at the beginning of the process, with respect to the precipitated solids), and the precipitate, it follows that intimate contact of the sludge with the liquid will hasten the change from a state

of supersaturation to one of saturation, which latter is the stable condition desired. This change is hastened by exposure of large areas of the precipitate to the liquid and by agitation. The practical significance of these conditions is apparent, since by thorough and rapid mixing of the reacting substances in solution, surface contact of the liquid with the precipitate, and agitation of the mixture, we bring about as complete a separation as it is possible to produce.

If we now consider the physical changes in themselves, which, as has been explained, must follow the chemical reactions, it is evident that the phenomena are practically all related to matter in the colloidal state. For example, Mr. J. F. Norton concisely sums up the colloidal reactions when aluminum sulphate is applied to natural waters as a coagulant, as follows:

> First, there is formation of a positively charged colloidal hydroxide. Second, this hydroxide reacts with the negatively charged bacteria and clay or other colloids. Third, the excess colloidal aluminum hydroxide is precipitated by agitation. Fourth, the positively charged coloring matter is precipitated by the negatively charged sulphate ion. Fifth, any color in true solution is adsorbed by the hydroxide.[4]

The mutual precipitation of oppositely charged colloidal particles appears to be the basis upon which most of the coagulation processes depend. It has been noted that the effect of an electrolyte upon a suspensoid is first of all to diminish the potential difference betwen the disperse phase and the medium, and precipitation only occurs when the potential difference has been brought sufficiently near to zero, the point of electric neutrality or the iso-electric point. A definite concentration of the electrolyte is evidently necessary for precipitation; and as smaller concentrations may cause only partial precipitation or even none at all, it is not improbable that larger concentrations may also produce partial or no precipitation. The analogy suggested between these principles and the facts well-known to operators of purification plants is worth noting. For example, it is almost always true that there is a minimum quantity of coagulant below which the most imperfect and unsatisfactory coagulation is obtained. Catlett several years ago found that a both highly colored and turbid water, which was a mixture of two waters which reached the filter plant before sufficient time had elapsed for mutual precipitation of the colloids, required the addition of alkali before the alum would pre-

[4] The Chemistry of Colloids, Zsigmondy, Spear and Norton.

cipitate. The color was not completely removed even then. By adding an excess of alum first, which gave an opportunity for the aluminum and sulphate ions both to act, and then introducing the alkali so that aluminum hydroxide would be formed, a satisfactory coagulation resulted with a much smaller quantity of the coagulant.[5]

The protective action of certain colloids in preventing coagulation is illustrated by the fact that a water containing considerable sewage requires more alum for purification than an unpolluted water having the same turbidity and color. The fact established by colloidal chemists, that by adding a reagent slowly to a colloidal solution more is required to produce precipitation than if added rapidly, may afford a possible explanation for some of the poor results obtained in some purification plants. The phenomena of adsorption, depending as it does principally upon the factor of "surface concentration," that is, upon the difference of concentration at the boundary between two heterogeneous phases, whether the phases be gas, liquid or solid, may account for many of the obscure and puzzling phenomena of the sand filtration of coagulated waters.

Like all new developments in science, colloidal chemistry has been seized upon to explain many phenomena which are complex, and which will eventually be found to require the formulation of entirely new and unrelated principles. If investigators, however, will bear in mind, that from the mass of facts, concerning the colloidal state of matter, principles and laws are slowly being developed and by use of which explanations of some of the obscure phenomena in coagulation, sedimentation and filtration of water, may be found, there may be a real advance in the art of water purification.

[5] *Engineering Record*, 73, 741 (1916).

A STANDARD BACTERIAL INDEX[1]

By P. V. Wells[2] and W. F. Wells[3]

1. INTRODUCTION

For a number of years one of the authors has been struck with the simplicity and convenience of the logarithm as a variable in bacteriology, and has recommended its use in a number of papers.[4] The practical value of these suggestions has never been questioned, but considerable reluctance has been shown toward their adoption, due apparently to doubts as to their sufficient basis in statistical theory. In the present paper this aspect of the dilution method is considered, and it is shown that from every point of view the appropriate bacterial index is the logarithm of the number of bacteria per liter.

The reason for the dilution method is the wide variability in bacterial populations. In investigating such distributions the observer must consider not only errors of measurement which change the value of the variate observed, due to imperfect apparatus and technique, but also those fluctuations in frequency which occur quite independently of the precision with which the variates are measured, which are errors of sampling. Only those variations in excess of errors of measurement and of sampling are characteristic of the bacteria themselves, and indicate local conditions and their changes with time.

If the bacteria are distributed at random throughout the sample of water, and the inoculations are made independently so that the variates are not correlated with each other, the theory of probabilities is able to predict the fluctuations of sampling. The mere presence of bacteria in a given dilution indicates a probable lower limit to the

[1] Published by permission of the Director of the Bureau of Standards.

[2] Associate Physicist, Bureau of Standards, Washington, D. C.

[3] Biologist, Conservation Commission, Albany, N. Y.

[4] W. F. Wells, Proc. Am. Water Works Assn., 1913; *U. S. Hygienic Laboratory Bulletin*, no. 104, 1916; Science, 47, p. 48, Jan. 11, 1918; *ibid.*, 49, p. 401, Apr. 25, 1919; *Am. Jour. Public Health*, 8, p. 904, 1918; *ibid.*, 9, pp. 664–667, 956–959, 1919; *Jour. Am. Water Works Assn.*, 8, pp. 187–190, 233–238, 1921.

number of bacteria in the original sample; a series of increasing dilutions, however, including both positive and negative tubes, is a combination of events which indicates very definitely the probable number. Unfortunately the errors of sampling are much larger than when the number of colonies is actually counted. But as it is the only method available for the estimation of B. coli, working rules for obtaining the bacterial index and its standard error of sampling are presented.

In the method of bacterial counts the error of sampling of a single plate is less than 30 per cent when the count is above 10 colonies per plate, and so is of no practical importance. While the bacterial index is found to be obviously the most convenient variable in the dilution positive method, the necessity of taking logarithms is a disadvantage in the method of counts. A consideration of the errors of measurement, however, shows that this labor is more than justified by increased stability in the averages. The bacterial index is therefore the appropriate variable for both methods.

A study of observed bacterial distributions in space and time amply confirms the wisdom of choosing the logarithm as a bacterial index. Distributions of this variable found in nature are approximately normal, so that discussion of their properties is much simplified. Moreover the index gives a more compact scale for routine work and the results are more easily correlated with other phenomena. But in spite of all these advantages some may feel that the number of bacteria is really a more fundamental and natural quantity, and that somewhow or other the use of the index is a contravention of statistical method; for the average index is the logarithm of the geometric mean number of bacteria, and the mere mention of this strange average gives rise to misgivings in their minds. To dispel such notions is not easy without entering into the maze of statistical theory. But an attempt will be made to explain as simply as possible enough of the theory of averages to justify the adoption of the bacterial index as a standard variable in bacteriology.

2. FUNDAMENTAL THEOREM

The first interpretation of fermentation tube results from the standpoint of random sampling was made by McCrady.[5] This

[5] McCrady, *Jour. Infect. Diseases*, 17, 183, 1915; *Pub. Health Jour.*, 9, 201, 1918.

was followed by the more complete study of Greenwood and Yule,[6] and a series of interesting papers by Stein.[7] The theoretical basis of their work is a theorem in probabilities first stated by the great French mathematician Poisson in 1837, which has often been called the "law of small numbers," or the "law of small chances." This law applies wherever rare individuals are distributed at random in a very large population, and sufficiently large samples are taken to include a few of the exceptions. It might be called the "law of exceptions in a crowd." As the bacteria are extremely rare compared with the number of equivalent water "particles" in which they are diluted, there can be little question of the applicability of "Poisson's exponential limit." It states that the chance (C_B) of (B) bacteria occurring in a sample containing (z) bacteria when uniform is

$$C_B = \frac{z^B}{B!} \exp(-z) \tag{1}$$

where the symbols denote the exponential (exp. $(-z) \equiv e-z$) and the factorial ($B! \equiv L^B$).

Poisson's law has been applied in a great variety of cases (usually in ignorance of the others), such as the frequency of rare diseases, the counting of blood corpuscles, the counting of α-particles emitted by radium, etc. A careful study of this law in Karl Pearson's laboratory by Whittaker[8] has revealed a number of unsolved questions, but for our problem the validity of equation (1) is quite sufficient.

In applying the fundamental theorem to the interpretation of the presence of bacteria and to determine the fluctuations in sampling, it must be remembered that actual conditions are far from the ideal. Instead of being distributed individually at random throughout the water as assumed by the theory, bacteria may and probably do grow in colonies and adhere to suspended particles. The experimental procedure also tends to interfere with the random distribution, for the dilutions are made in steps and thus are not separate samples. The identification and counting present still further problems.

Thus, while the theory of probabilities as applied to this case assumes perfect irregularity and independence in the "contributory

[6] Greenwood and Yule, *Jour. Hygiene*, 16, 36, 1917

[7] M. F. Stein, *Am. Jour. Pub. Health*, 11, 820–9, 1918; *Jour. Bacteriology* 4, 243–65, 1919; *Eng. News Record*, 82, 1106–9, 1919.

[8] Lucy Whittaker, *Biometrika*, 10, 36–71, 1914. The function is tabulated in Pearson's Tables (51).

cause-groups" (for curiously enough these very cases are the simplest), there can be little question that bacterial results are somewhat correlated. But it is in this borderland between perfect independence and perfect causality, i.e., in the field of correlation, that the phenomena defy analysis. It is hardly worth while to introduce these complications until the simpler cases are well understood. The theory can be regarded as a first approximation, giving the general march of the phenomena, just as it is applied to slightly "loaded" dice or to imperfect cards in other games of chance. The value of mathematics lies in the clearness of its reasoning, but its very exactness excludes from practical discussion much of the complexity of nature.

3. THE BACTERIAL INDEX

The usual procedure in bacteriology, when plates are not counted, is to record simply the presence or the absence of colonies at each dilution. Observations "bacteria present" are marked positive (+), those "no bacteria present" are marked negative (−). The dilutions are made on a geometric scale. This "dilution scale" can be formed merely by assigning serial numbers 1, 2, 3, 4, 5, 6, etc., to the dilutions containing 100 cc., 10 cc., 0.1 cc., 0.01 cc., 0.001 cc., etc., of the original sample in the inoculation; the "dilution" (d) represents the common logarithm of the number of bacteria *per liter* in the original sample for each bacterium in the dilution. The *bacterial index* (x), or logarithm of the number of bacteria per liter, is therefore

$$x = d + \log z \tag{2}$$

where (z) is the number in the inoculation at dilution (d). For example, one bacterium in 0.001 cc. of the original sample ($z = 1$, in $d = 6$) gives an index $x = 6$, or 10^6 bacteria per liter.

The chance (C_0) of observing no bacteria in the inoculation is, by (1),

$$C_0 = \exp(-z) \tag{3}$$

and the chance of a positive tube is $(1 - C_0)$. The chance of dilution, (d) being positive and $(d + 1)$ negative, is the product of their separate probabilities, *if the dilutions are independent.* Thus the probability $(C_+ -)$ of the series

$$\begin{pmatrix} d, & d+1 \\ + & - \end{pmatrix} \text{ is } C_{+-} = \left[1 - \exp(-z)\right] \exp\left(-\frac{z}{10}\right) \tag{4}$$

and the most probable value of (x) is $x_m = d + 0.38$, for $z = \ln 11$ is the mode of (4). But the observed series should extend through all dilutions, giving $(\ldots ++{+}{-}{-}{-}.\ldots..)$, the last positive dilution being at (d). This dilution is then called the "dilution positive" $(d+)$. The probability (C_{d+}) of this series is

$$C_{d+} = \ldots..\,[1-\exp(-10^2 z)]\,[1-\exp(-10z)]\,[1-\exp(-z)]$$
$$\exp\left(-\frac{z}{10}\right)\exp\left(\frac{z}{10^2}\right)\ldots.. \qquad (5)$$

The mode of this function is $z = \ln 10.1$, so that the most probable value of the bacterial index (x_m) is

$$x_m = d_+ + 0.364 \qquad (6)$$

In words, if samples of water of various bacterial contents be observed to give the endless series of dilutions in which all dilutions less than and including (d_+) are positive, all greater negative, that sample for which $x = d_+ + 0.364$ will be observed most frequently. This is the correction to be applied to an observed "dilution positive" (d_+) to get the most probable bacterial index (x_m).

When the test by a series of dilutions is repeated many times upon the same sample of water, the dilution positive (d_+) is found to vary from test to test, so that the correction (6) is not of much use in practice. Moreover the most frequent series $(+++{-}{-}{-})$ is not the only type observed. "Skips" sometimes occur, such as $(++{-}{+}{-}{-})$; it seems logical to "revert" these after the manner of Phelps, that is permute $(-)$ and $(+)$ to give the regular order $(+++{-}{-}{-})$.

One mode of procedure is to develop a general expression like (5) with the percentages positive and negative as unknowns (see equation 14) and then solve for the most probable value (x_m). This is feasible when the number of dilutions considered is limited, and we shall use it later (article 7) for incomplete tests; but the solution is too complicated in the general case.

4. THE AVERAGE BACTERIAL INDEX

It is often simpler to find the average value by means of the probability function than to find the mode, or most probable value. Suppose the test by a series of dilutions is repeated many times upon the same sample of water, of given index (x), what average dilution

positive is to be expected? Expressions similar to (5) give the chances of any given dilution positive (d_+). Now these probablities are the frequencies in very large series of tests, so that the average dilution positive is formed simply by adding the products of each (d_+) by its frequency (C_{d+}). This quantity ($\bar{d}_+$) is found to differ from the bacterial index (x) merely by an additive constant, thus leading to a working rule of remarkable simplicity.

Taking the dilution (d) as origin, with (n) larger dilutions ($d+1$, $d+2, \ldots d+n$), and n smaller, there are ($2n+1$) dilutions in the series. Now these dilutions may be all positive, all negative, or any other arrangement of positive and negative, in all

$$2\left[\frac{(2n+1)!}{(2n+1)!}+\frac{(2n+1)!}{2n!\,1!}+\frac{(2n+1)!}{(2n-1)!\,2!}+\cdots\cdots+\frac{(2n+1)!}{(n+1)!\,n!}\right]$$

different permutations. Working out the probabilities of each of these, after the manner of (5), multiplying each by its dilution positive, and adding, the bacterial index (x) is obtained as a function of the average dilution positive ($\bar{d}_+$). By inductive reasoning the general expression is found to be

$$x=\bar{d}_+ +\left[C_0^{\frac{1}{10n}}+C_0^{\frac{1}{10n-1}}+\ldots+C_0^{\frac{1}{10}}+C_0+C_0^{10}+C_0^{10^2}+\ldots+C_0^{10^n}+\log z-n\right] \quad (7)$$

where $x = d + \log z$, and $C_0 = \exp(-z)$.

Fortunately the correction term in brackets is practically constant. The number of dilutions ($2n+1$) need not exceed the number of significant figures to which the probabilities are computed; but (n) can always be taken very large, for increasing (n) merely adds unit and zero terms, and the unit terms exactly cancel the increase in (n). Now the correction has the same value for all multiples of (z) by a power of 10, for the change in the unit terms is exactly compensated by the change in ($\log z$). It is therefore necessary to consider values of (z) between 1 and 10 only. A few values are shown in table 1. The correction is very nearly constant; the one to be chosen is obviously that corresponding to the most probable value of (z), namely: $z = \ln 10.1 = 2.313$, which gives

$$x = \bar{d}_+ + 0.231 \quad (8)$$

The correction will not often exceed 0.24, and cannot exceed 0.27.

The fluctua ions of sampling a single specimen of water can be eliminated, therefore, by taking the average dilution positive

reverting skips) and adding + 0.24. In actual practice, however, a single specimen is not of sufficient importance to warrant such effort. Each sample tested is from a different locality, and at a different time. An average of the bacterial contents is desired. Does the same correction to the average dilution positive of such space and time distributions give the average bacterial index? A little consideration shows that this method of averaging compensates for the fluctuations in sampling in one case as in the other. The compensation would be complete if sufficient samples were taken and the correction (7) did not vary with (z), for then the deviations would be simply additive. But we have shown in table 1 how nearly constant the corrections are. Moreover, the correction for the mode is a mininum, so that it is changing most slowly just where the values of (z) are most numerous. It is therefore reasonable to assume that the correction will rarely exceed + 0.24.

TABLE 1

$z =$	1	2	3	4	5	6	7	8	9
$x = \bar{d} + +$	0.262	0.233	0.235	0.247	0.258	0.265	0.267	0.267	0.265

The proper working rule is thus: *Add $\frac{1}{4}$ dilution (or + 0.24) to the observed average dilution positive $(\bar{d}_+)$ to find the average bacterial index $(\bar{x})$ of any distribution.*

5. THE STANDARD ERROR OF SAMPLING

To illustrate the method by which (8) is reached, a series of three dilutions is worked out numerically in table 2, choosing $z = 2.313$.

From table 2 an interesting conclusion can be drawn as to the fluctuation of sampling in the dilution positive method. In the last column the second moment is computed, giving for the standard error of sampling of the dilution positive $\sigma = 0.523$. A similar computation for $z = 1$ gives $x = \bar{d}_+ + 0.258$ and $\sigma = 0.589$. A good figure for the standard error of sampling of the dilution positive is therefore

$$\sigma = 0.55 \tag{9}$$

The standard error of sampling of the average dilution positive of N tests is therefore

$$\sigma_N = \frac{0.55}{\sqrt{N}} \tag{10}$$

TABLE 2

OBSERVED SERIES DILUTIONS			FREQUENCY	DILUTION POSITIVE		
d	$d+1$	$d+2$	C	d_+	$d_+ \times C$	$d_+^2 \times C$
			per cent		*per cent*	*per cent*
+	−	−	69.9	d		
+	+	−	18.2	$d+1$	+18.2	18.2
−	−	−	7.7	$d-1$	−7.7	7.7
−	+	−	2.0	d		
+	−	+	1.6	$d+1$	+1.6	1.6
+	+	+	0.4	$d+2$	+0.8	1.6
−	−	+	0.2	d		
+	+	+	0.0	$d+1$	+20.6	29.1
					−7.7	.017
					+12.9	$\sigma^2 = 0.274$
Total frequency.....			100.0	$\bar{d}_+ = d$	+0.129	$\sigma = 0.524$

Bacterial index (log. bacteria per liter) $x = \bar{d} + + 0.235$

Thus apart from any errors of measurement, a standard deviation must exceed 0.55 to indicate any significant variation in the bacterial distribution.[9]

How do these ideal conditions compare with actual experience? The most extensive series of tests are those compiled by Wolman [10] for the distribution of B. coli in tap water. From his data we get the following results:

TABLE 3

B. coli in tap water

YEAR	NUMBER TESTS (N)	AVERAGE DILUTION POSITIVE ($\bar{d}_+$)	INDEX ($\bar{x}$)	STANDARD DEVIATION OF SINGLE TEST ($\sigma_N\sqrt{6}$)
1917	267	1.44	1.68	1.23
1918	202	1.24	1.48	1.08
1917–1919	614	1.23	1.47	0.81

The standard deviation (σ_N) in the last column is multiplied by $\sqrt{6}$ because each of his variates is an average of 6 tests. Now if the

[9] The ratio of the standard deviation to the standard error of sampling is sometimes called the "Lexian ratio." The random sampling of independent variates is called by Yule "simple sampling," to distinguish it from the random sampling of correlated variates.

[10] A. Wolman, this JOURNAL, 7, 927–930, 1920.

B. coli index for tap water be kept below 1.47 with a permissible standard deviation of 0.81, over half of this deviation may be accounted for by the standard error of sampling 0.55. This illustrates the significance of such fluctuations in the estimation of B. coli.

Wolman found the cumulative diagram to be a straight line when plotted on logarithmic probability paper. This shows that the distribution of the index is normal or the law of error. The corresponding distribution for the variable (X), the number of bacteria per liter, is therefore normal geometric, and the geometric mean ($\overline{X}$), which is simply the antilogarithm of the average bacterial index ($\bar{x}$), is the *median* of the X-distribution. It will be shown later that the variability ($V \equiv \sigma_x/\bar{x}$) of normal geometric variation is given by the relation $V = \sqrt{\exp(5.30\,\sigma_x^2) - 1}$, so that the last row of table 3 gives $\overline{X} = 30$ B. coli per liter with a variability of 560 per cent. The corresponding variablity due to sampling is 200 per cent from (9). It is evident what a large factor should be reserved in all such estimates of bacterial content.

From this point of view the dilution scale and the index have the obvious advantage of uniform coarseness, giving no false impression of precision and wasting no figures in expressing large numbers. For example, an index 10 represents a bacterial content which is rarely reached even in the worst sewage, while an index 1.5 represents tap water. This convenient geometric scale is provided in the simplest manner imaginable, merely by assigning serial numbers 1, 2, 3, 4, etc., to the successive dilutions containing 100 cc., 10 cc. 1 cc., 0.1 cc., etc., of the original sample, and then observing the average dilution positive.

6. INTERPRETATION OF THE DILUTION POSITIVE METHOD

It is interesting to note that much simpler conditions lead to about the same correction as (8). Thus ignoring all dilutions except (d) and ($d + 1$), assume that the chance of the former being positive equals the chance that the latter is negative. The condition is $1 - \exp(-z) = \exp(-0.1\,z)$, which gives the solution $x = d + 0.255$. The same equation expresses the condition that either (d) or ($d + 1$) must be positive; it also follows if one of these dilutions must be negative. All three of these conditions are logical and consistent, but an examination of table 2 shows that they ignore too many facts to have much weight.

It may be remarked that taking the "dilution positive" as variate is equivalent to forming a weighted average of all the dilutions, assigning to the dilution (d) the weight ($-\Delta P = P_d - P_{d+1}$). Here ($P_d$) is the frequency of positive tests in dilution (d), (P_{d+1}) is this frequency in the next dilution. Since $\Sigma(-\Delta P) = 1$, we have for the weighted average dilution

$$\bar{d}_+ = \sum_{-\infty}^{\infty} d\,(-d\Delta P \tag{11}$$

Now we can see the effect of changing the dilution interval, for when $\Delta d \to 0$, this weighted average becomes

$$\bar{d}_+ = -\int_{-\infty}^{\infty} d\,\frac{\partial P}{\partial d}\,\delta d = -\int_{0}^{\infty} \exp(-z)\left[x - \frac{\ln z}{\ln 10}\right]\delta z \tag{12}$$

since $d = x - \log z$, and $1 - P = \exp(-z)$. Integrating,

$$x = \bar{d}_+ - 0.242 \tag{13}$$

showing that the correction decreases with the dilution interval, vanishing at about half-dilutions, and becomes negative for infinitesimal intervals.

It is also evident from (12) that averaging dilutions (d) instead of (x) is neglecting the factor $\log z$, and that it is the weighted average of this neglected factor which gives the nearly constant correction $+\frac{1}{4}$, when $\Delta d = 1$. But one must adopt some arbitrary system of weighting, for dilutions which are all positive or all negative cannot all possess the same significance. Stein[11] would discard all dilutions for which (P) is above 85 per cent or below 30 per cent. The simpler procedure of averaging the dilutions positive accomplishes the same result. He also recommends at least 10 tests in forming an average. By (10) this reduces the standard error of sampling of the mean index to $\frac{0.55}{\sqrt{10}} = 0.174$, which corresponds to a variability in the mean of normal geometric variation of 42 per cent.

In practice the method of weighting indicated by (11) is very simple as is shown in the example, table 4. The results of tests on

[11] M. F. Stein, *Jour. Bacteriology*, 4, 243–265, 1919.

($N = 10$) samples are recorded in the columns numbered 1–10, each tube opposite its dilution shown in the first column. Counting the number of positive tubes in each dilution, take first differences ($-N\Delta P$), then the partial moments ($-dN\Delta P$) and second moments ($-d^2N\Delta P$), etc.

TABLE 4

Example of dilution positive method

DILUTION (d)	1	2	3	4	5	6	7	8	9	10	(NP)	($-N\Delta P$)	($-dN\Delta P$)	($-d^2N\Delta P$)
3	+	+	+	+	+	+	+	+	+	+	10	3	9	27
4	+	+	−	+	+	−	+	+	−	+	7	4	16	64
5	−	−	−	+	−	+	−	+	−	+	3	2	10	50
6	−	−	−	−	−	−	−	+	−	−	1	1	6	36
7	−	−	−	−	−	−	−	−	−	−	0	0	0	0
											$N = 10$		41	177
														168
											$\bar{d}_+ = 4.1$		$\sigma^2 = 0.9$	
													$\sigma = 0.95$	
													$\frac{\sigma}{\sqrt{10}} = 0.30$	

Average bacterial index $\equiv \bar{x} = 4.34 \pm 0.30$

Geometeric mean bacteria per cubic centimeter $\equiv \overline{X} = 22 \pm 78$ per cent

7. INCOMPLETE TESTS

The average dilution positive cannot be applied to very pure waters in which less than 37 per cent of the tubes are positive in dilution 1 (containing 100 cc. of the sample), for it is inconvenient to complete such tests by including inoculations of 1 liter, 10 liters, etc., until the "dilution positive" is located. Such cases, moreover, will become more important as the standards of purity for water supplies are improved. It is fortunately a very simple matter to compute the most probable number of bacteria for such incomplete tests.

Suppose that a sample of water containing (X) bacteria per liter be tested, taking (v_1, v_2, v_3,), etc., liters as inoculations, and making (N) tubes at each of these volumes, with results (P_1N) positive, (Q_1N) negative in (v_1), (P_2N) positive, (Q_2N) negative in (v_2), etc. Then the probability of this result is, after the manner of (5),

$$C = \exp(-Xv_1Q_1N)[1-\exp(-Xv_1)]^{P_1N}\exp(-Xv_2Q_2N)[1-\exp(-Xv_2]^{P_2N} \ldots\ldots(14)$$

It will be noticed that this is exactly the integrand of Greenwood and Yule's[12] general expression. The most probable value of (X) is therefore given by the maximum condition

$$\Sigma i\left(1-\frac{Pi}{Mi}\right)V_i=0 \tag{15}$$

where $M_i \equiv 1-\exp(-v_i)$ is the most probable fraction positive in tubes containing volume (V_i), while (P_i) is the fraction actually observed. The mean of this ratio, weighted by the $(v$'s), is therefore unity.

This expression is unworkable in the case of a complete test; but suppose that three volumes only are taken, the 100 cc., the 10 cc., and the 1 cc., giving the fractions positive (P_1), (P_2), (P_3), respectively. Assume, moreover, that $P_1 < 37$ per cent. In this case we get the very simple approximate expression[13]

$$X_m = 9(P_1+P_2+P_3) \tag{16}$$

The most probable number of bacteria per liter (X_m) *is therefore simply nine times the sum of the fractions positive in dilutions 1, 2, and 3 (100 cc. 10 cc., 1 cc.), when the fraction positive in dilution 1 is less than 25 per cent.*

When the fraction positive in dilution 1 is greater than 37 per cent, the most probable value for dilution 0 is 100 per cent positive and so we may apply the ordinary method as in table 4. In other words, the test may be made complete by taking dilution 0, 100 per cent positive. The most probable value for the bacterial index (x_m) is simply

$$x_m = \log\left[100\,(P_1+P_2+P_3)\right]-1.05 \tag{17}$$

Applying (16) and (17) to Greenwood and Yule's two examples, we get immediately the results in table 5.

[12] Greenwood and Yule, *Journal of Hygiene*, 16, 36–54, 1917–1918. Our development is similar to theirs, but we arrive at a simple working rule.

[13] The derivation of this expression is rather long. Taking $v_3 = 10v_2$, $v_1 = 100v_2$, we get, neglecting higher powers of $X_m v_2$,

$$X_m = -\frac{1}{v_2}\ln\left[1-\frac{2(P_1+P_2+P_3}{222+9P_1+99P_2+108P_3}\right]$$

which reduces to (16) when $v_3 = 10^{-3}$ liters, and $P_1 < 0.37$, etc. (It is fairly simple to check this for two dilutions.)

The simple formula gives values far more precisely than is needed, considering the very large errors of sampling to which the method is susceptible. As the values of (P_1) increase the approximation becomes poorer until at 25 per cent the errors of (8) and (17) are about equal. At $P_1 = 25$ per cent (17) gives $x_m = 2.5$, the correct value being $X = 2.9$, while (8) gives $\overline{X} = 3.3$ bacteria per liter, so that the errors in the formula (16) never exceed 13 per cent. For values of (P_1) above 25 per cent it is better to use (8). At 37 per cent to assume that $P_0 = 100$ per cent introduces no error in the average dilution positive.

TABLE 5

B. coli in very pure water

DILUTION (d)	SOURCE A $N = 338$	SOURCE B $N = 333$
1	Number positive 30	21
2	5	6
3	2	4
	37 = 0.109	31 = 0.0931
	338 × 9	333 × 9
	$\overline{X}_m$ = 0.981	0. 838 per liter
Values of Greenwood and Yule	= 0.965	0.838
Bacterial index $\equiv x_m$	= −0.02	−0.08

Now suppose that it is not desirable to use as much as 100 cc. for an inoculation but that the three dilutions 2, 3, 4 (10 cc. 1 cc., 0.1 cc.) are included in the test, and that $P_2 < 25$ per cent. The most probable bacterial index is then

$$x_m = \log [100 (P_2 + P_3 + P_4)] - 0.05 \qquad (18)$$

or the most probable number of bacteria per liter is roughly equal to the sum of the percentages positive in the three dilutions. It is always preferable, however, to include inoculations large enough to get at least 37 per cent positive tubes, for the errors of sampling are probably much larger when the tests are incomplete.

8. THE METHOD OF BACTERIAL COUNTS

Whenever it is possible to count the actual number of colonies at each dilution, as in the plating method, the errors of sampling can

be reduced to negligible proportions. The fundamental theorem (1) gives directly for the arithmethic mean bacterial count ($\overline{B}$)

$$\overline{B} = \sum_{0}^{\infty} B\ (BC_B) = z \tag{19}$$

and for the standard deviation (σ_B) from it

$$\sigma_B^2 = \sum_{0}^{\infty} B\ (B - \overline{B})^2\ C_B = z \tag{20}$$

The variability (V) of sampling is therefore $V = \sigma_B/\overline{B} = 1/\overline{B}\sqrt{z}$, so that for plates with $z = 10$ colonies the variability is 30 per cent, while for $z = 100$ this is reduced to 10 per cent. These figures are halved for averages of four plates, and are reduced by the factor $1/\sqrt{N}$ for averages of N variates. Obviously fluctuations of sampling are of little moment in the method of bacterial counts.

The average number of bacteria per liter is simply calculated by the formula $\overline{X} = \overline{DB}$, where ($B$) is the count at dilution D = antilog $d = 1/v$, ((v) is the volume of the inoculation in liters). To form the average bacterial index ($\bar{x}$), the logarithm of each count must be taken. That is,

$$\bar{x} = \bar{d} + \bar{b}, \text{ where } b \equiv \log B \tag{21}$$

For this a two-place table is sufficient (table 6).

TABLE 6

Two-place logarithms

	0	1	2	3	4	5	6	7	8	9
1	00	04	08	11	15	18	20	23	26	28
1	30	32	34	36	38	40	42	43	45	46
3	48	49	51	52	53	54	56	57	58	59
4	60	61	62	63	64	65	66	67	68	69
5	70	71	72	72	73	74	75	76	76	77
6	78	79	79	80	81	81	82	83	83	84
7	85	85	86	86	87	88	88	89	89	90
8	90	91	91	92	92	93	93	94	94	95
9	95	96	96	97	97	98	98	99	99	00

The geometric mean number of bacteria ($\overline{X}$ = antilog $\bar{x}$) which corresponds to the average index is smaller than the arithmetic

mean ($\overline{X}$), and for moderate variabilities is given by the approximate relation[14]

$$\overline{X} = \overline{X} - \tfrac{1}{2}\frac{\sigma^2}{\overline{X}} \tag{22}$$

Now the most probable bacterial count (B_m) is found from Pearson's slope relation to be $B_m = z - \frac{1}{2}$. Comparing (19), (20), and (22), we have

$$\overline{X} = D(z - \tfrac{1}{2}) = X_m \tag{23}$$

so that *the mode of Poisson's exponential limit is closer to the geometric mean than to any other simple average.* This disposes of any theoretical objections to the use of the geometric mean count as the most probable number of bacteria in a given sample. The variability is so slight, however, that any difference between the arithmetic and geometric means must be due either to experimental errors or to the bacterial distribution in space or time.

9. THE STABILITY OF AVERAGES

We have examined three experimental procedures, obtaining simple working rules for the bacterial content (1) from the average dilution positive, (2) from the total per cent positive in three dilutions and (3) from the bacterial count itself. In the two latter cases the number of bacteria is more simply computed than is the bacterial index. In the first case only is the index found with less labor. But a study of the errors of measurement shows the real reason for preferring the average index, and its antilogarithm the geometric mean.

The essential property of an average, that which makes it more useful than any individual observation, is its stability. Its value must be representative of all the data, not dominated by a few. Now in any case where the data vary widely a few very large values, representing perhaps less than one per cent of the results, may halve or double the value of the arithmetic mean; their effect upon the geometric mean is but slight. This renders the arithmetic mean practically valueless in distributions of wide variability.

This point can be seen immediately from a consideration of the frequency curve. As Pearson has shown, the ordinate representing the arithmetic mean passes through the center of gravity of the frequency curve. Now in cases of wide variability the curve runs

[14] See Yule, Theory of Statistics, 3rd ed. p. 156, London, 1916.

out to enormous values, in a very long "tail." The lever-arm of these extreme values is tremendous, so that one such result dominates hundreds of ordinary ones. The value of the arithmetic mean is determined not by the large numbers of usual results but by the few chance "huge" ones. The procedure of discarding arbitrarily all observations of this class is not so satisfactory as the determination of the geometric mean, which gives each observation equal weight on a proportional scale.

It is difficult for one habituated to the small variations of the physical sciences to appreciate the effect of wide variation on the arithmetic mean. Take the following illustration from an actual bacteriological distribution.[15]

TABLE 7

OBSERVATIONS PER 1000 ΔN	BACTERIA PER LITER X	$X\Delta N$	$\log X$ x	$x\Delta N$
1	10	10	1	1
29	100	2,900	2	58
120	1,000	120,000	3	360
452	10,000	4,520,000	4	1,808
311	100,000	31,100,000	5	1,555
79	1,000,000	79,000,000	6	474
8	10,000,000	80,000,000	7	56

$\Sigma X\Delta N = 194{,}742{,}910$ $\Sigma x\Delta N = 4{,}312$

Arithmetic mean $\overline{X} = 195{,}000$, geometric mean $\overline{X} = 20{,}500$

Same, omitting last 8 observations $\begin{cases} \overline{X} = 116{,}000 \\ \overline{X} = 19{,}500 \end{cases}$

Percentage change $\begin{cases} (\text{in } N)\ 0.8 \text{ per cent} \\ (\text{in } \overline{X})\ 41 \text{ per cent} \\ (\text{in } \overline{X})\ 4.9 \text{ per cent} \end{cases}$

By omitting the last eight observations (in one thousand) the arithmetic mean is reduced over 40 per cent, more than eight times the change in the geometric mean. A glance at the last column shows that the geometric mean is not much affected by where the "tail" is cut off, whereas there is no indication that even one thousand observations are enough to determine the arithmetic mean. The same point is shown graphically in figure 1, the total areas representing first moments. The arithmetic mean is quite indeterminate.

[15] Sir A. C.Houston, *Journal of Pathology and Bacteriology*, 18, 351, 1913–14.

One may reply that a single value cannot be expected to represent such a wide distribution. This is perfectly true, the variability is here perhaps the most important feature. But the lack of stability

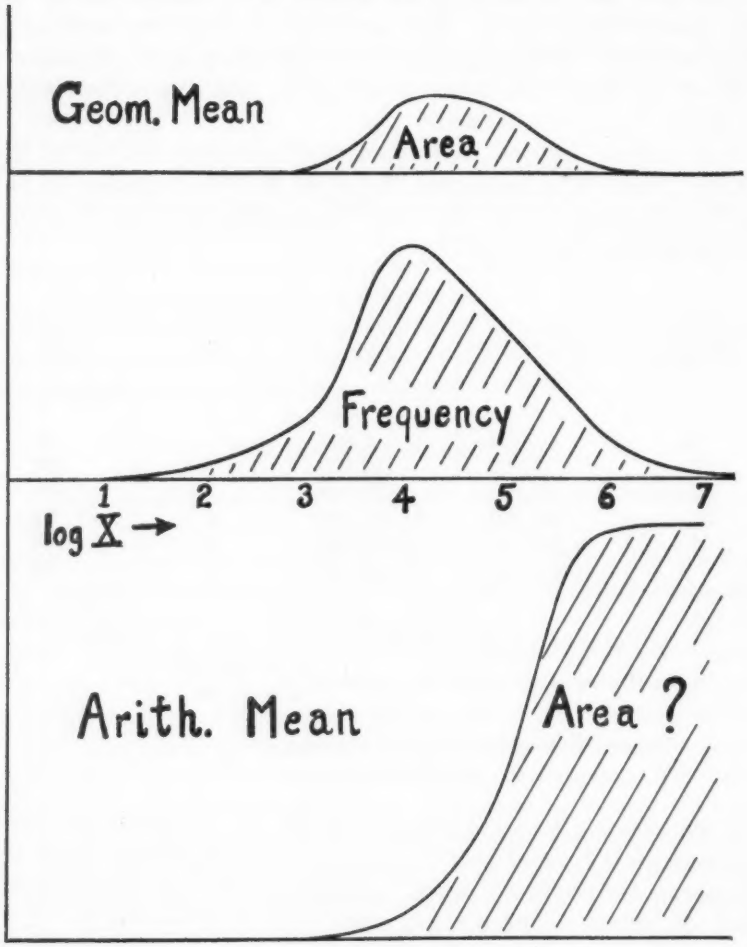


FIG. 1

of the arithmetic mean is even outdone by the instability of the standard deviation, and it is still worse for the higher moments. These constants which the Pearson school of statistics has taught us to regard as the most important characteristics of the distribution,

cannot be determined with precision even from a thousand observations. Pearson has called attention to the necessity of extremely large numbers of observations in order to overcome the fluctuations of sampling, but apparently no one has appreciated the immense superiority of the geometric mean in this regard.

In using the arithmetic mean each variate should be measured with the same absolute precision, for errors in the mean are simply $(1/N)$'th of the errors in the variate. This requires a variate 1,000,000 to be known to 6 significant figures if the variate 1000 is known to 3 figures. This is all right in a bank, where a check for a million dollars must be recorded to the last penny. But what is the case in bacteriology? It is precisely the *large variates* which are the *least reliable*, not only absolutely but *even proportionally*, for they have been subjected to more dilutions. An absolute error of 1000 bacteria in the variate 1,000,000 is *more* probable than is an error of 1 bacterium in the variate 1000. Taking the arithmetic mean is equivalent to treating the better *variate* as an *error* of the worse variate. Yet bacteriologists hesitate in adopting the geometric mean.

The point is simply stated mathematically. The same proportional error in the variate (X) produces the proportional error $(\Delta\overline{X}/\overline{X})$ in the arithmetic mean $(\overline{X})$ and the proportional error

$$\frac{\Delta\Gamma\overline{X}}{\Gamma\overline{X}} = \frac{\overline{X}}{X} \cdot \frac{\Delta\overline{X}}{\overline{X}} \tag{24}$$

in the geometric mean $(\overline{X})$. The same effect is illustrated graphically in figure 2, showing the percent error in the means resulting from a given per cent error of frequency in the variate (X). The superiority of the arithmetic mean for small variates is of little importance compared with its grave defects for very large ones. The harmonic mean (the reciprocal of the average reciprocal) is even less affected by errors in large variates than is the geometric mean, and would form an interesting index, leading to expressions of "volumes contain 1 bacillus," "dilutions (D)" etc. But the harmonic mean overemphasizes negative results and the reciprocal possesses inconveniences as a variable.

Suppose the same absolute error to be made in each variate, increasing each (X) to $(X + \epsilon)$. The arithmetic mean is increased the same amount (ϵ), but the geometric mean is increased more proportionally. If each variate be increased by the same proportion

$(X(1+\epsilon))$, the arithmetic and the geometric mean are both increased in the same proportion. But if larger variates are increased in greater proportion, the proportional increase in the arithmetic mean is greater than that in the geometric mean, and this superiority of the geometric mean increases rapidly with the variability. This is precisely the case in bacteriology, for even proportional errors of measurement are larger in the larger variates.

The stability of the geometric mean is very real even in extensive series of samples. Its greatest utility, however, is when few samples

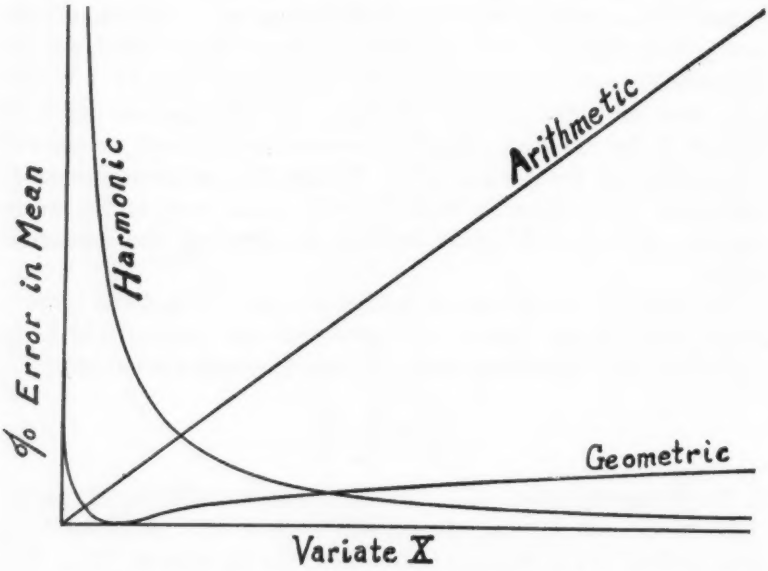


FIG. 2. ERROR IN MEAN DUE TO FLUCTUATION IN FREQUENCY

are taken. In actual practice it will be found that significant tendencies and relations can be discovered in geometric means when the arithmetic means are hopelessly erratic. Or, from another point of view, the same results can be obtained from fewer observations. The stability of the geometric mean extends in like measure to its logarithm, the average index. Indeed the chief value of this variable is that it avoids one computation in routine work. Why should one bother to find $(\overline{X})$ when $(\bar{x})$, a more convenient variable, is at hand? Of course, in reports and popular illustration the geometric mean should be used; it can be called simply the "usual number of bacteria per liter." But in graphs the index is almost necessary.

10. THE CHOICE OF AVERAGE

There has been considerable reluctance on the part of bacteriologists to using the geometric mean, not on any "practical" grounds, but because they fear it as a contravention of statistical theory. In fact, the elegant systematic methods of Pearson appear to exclude any average but *the* (arithmetic) mean. The variates (observations) are grouped, the frequency distribution formed, and the moments give the mean, standard deviation, etc., in the simplest manner. But the choice of character to be observed is *quite arbitrary*, a fact usually passed over in silence. Considerations of convenience dictate this choice, and such considerations may likewise indicate a change of variable at the very start of the investigation. The simple average in this new variable corresponds to quite a different type of average of the variates. If the logarithm is used as variable, the variate average is the geometric mean. The geometric mean is therefore perfectly consistent with Pearson's theory.

The fact that averages change with change of variable completely alters our point of view with regard to them. The choice of variable, as of observed character, is arbitrary, a matter of convenience, This cannot be too strongly emphasized, because many scientific workers have a vague notion that *the* (arithmetic) mean is ordained by the "laws of chance." If chance ordains any average, it is the median, for this is the only average which retains the same significance regardless of the variable chosen. Indeed Laplace,[16] the greatest authority in this subject, chose the *median* as fundamental, in spite of the fact that previous mathematicians had chosen the *mode*, or most probable value. But the mode changes with changing variable as do all averages except the median.

The problem is as old as Galilei,[17] who was called in by his Florentine friends to answer the following question: a horse is really worth a

[16] Laplace, Théorie Analytique des Probabilités, *Nat. Ed. Livre*, II, no. 23, p. 340. "Des geomètres célèbres ont pris pour le milieu qu'il faut choisir celui qui rend le résultat observé le plus probable, et par conséquent l'abscisse qui répond à la plus grande ordonnée de la courbe; mais le milieu que nous adoptons (median) est évidemment indiqué par la théorie des probabilités." To Laplace the median was the *most advantageous* value, because it rendered the sum of the deviations (taken without regard to sign) a minimum. The arithmetic mean renders the sum of the squares of the deviations (from it) a minimum. Both criteria are arbitrary.

[17] See I. Todhunter, *History of the Theory of Probability*, p. 5, Macmillan, 1865.

hundred crowns. One person estimated it at ten crowns, another at a thousand. Which is the more extravagant estimate? He pronounced the two estimates equally extravagant, anticipating Fechner's law of sensation. The priest Nozzolini pronounced the higher estimate the more extravagant—sound business practice. This apparently trivial question illustrates perfectly the usual ambiguity of purpose in the choice of averages.

Jevons[18] introduced the geometric mean into practice, to obtain an index number for prices. He was much impressed with its importance, considering that "in almost all the calculations of statistics and commerce the geometric mean ought, strictly speaking, to be used." Galton[19] concluded similarly: "in short, sociological phenomena, like vital phenomena are, as a general rule, subject to the condition of the geometric mean." Unfortunately natural phenomena are not so ideally simple, upon either a geometric or an arithmetic scale. In many cases variation can be best regarded as the product of factors, and then proportional changes appear natural. Thus we consider the effect of environment upon an object, or of the surroundings upon a system. But in general the causes determine the magnitude of the variate neither by their sum nor by their product.

The choice of average is therefore a matter of practical compromise. When the purpose in hand is sufficiently definite, the suitable average is often very complicated. Economists have carried the theory farthest, in their search of an index number for prices. Recent studies by Walsh and Fisher[20] have shown that the geometric mean of two weighted arithmetic means is required. Can there be any doubt that in most cases the choice of the arithmetic mean rests merely on the desire for simplicity?

A change of variable often introduces simplicity in scientific laws. For example, the change from cartesian to spherical or cylindrical coördinates, from cordinates to "generalized coördinates" and from velocities to momenta in mechanics, from centigrade to absolute temperature, from pressure, temperature and volume to "corresponding" pressure, etc., in the theory of corresponding states, and from wave-length to frequency in optics. Of course, these theories assume perfect causality, so that fixing all variables except one is supposed

[18] W. S. Jevons, *Fall in Value of Gold*,1863, *Principles of Science* (Am. Ed.) p. 419, 1873.

[19] F. Galton, *Proc. R. S.*, 29, 365–76, 1879; *ibid.*, 40, 42–73, 1886.

[20] Irving Fisher, *Am. Stat. Assn. Quarterly*, March, 1921.

to determine exactly the value for that variable. But in nature variates are merely correlated, and "natural quantities" are actually averages of distributed variates. Now the question arises: In which variable shall we compute the average? In other words: What average shall we use? For if (A) denote the average of the variable (X) corresponding to the simple average $(\bar{x})$ of the variable $x = f(X)$, we have

$$f(A) = \frac{1}{N} \Sigma f(X) \tag{25}$$

Taking the arithmetic mean of the observed character is no solution, for who shall decide which variate shall be observed? Bertrand[21] has remarked that there is no a priori reason for expecting that one function rather than another of the variate should vary by simple chance; and Pearson has more recently shown that the normal law is really too simple to describe the vast majority of frequency distributions. The conventional character of scientific method is obvious. No general rule can be given for choosing the appropriate average. The criterion must be convenience. For specific purposes certain conditions may decide the question, as the equation of exchange requires particular properties in an index number for prices. If experience is wide enough, however, probably no single average will suffice for all purposes.

11. NORMAL GEOMETRIC VARIATION

The consideration of change of variable in statistics leads to interesting questions regarding the frequency distributions arising from random sampling. To every type of variation of the variates corresponds an unlimited number of different types for the various functions of the observed variable. Pearson has shown that the first four moments, giving the mean, variability, skewness, and kurtosis respectively, are sufficient for describing actual frequencies within the errors of random sampling. By change of variable, however, it may be possible in certain cases to reduce the order of such freqnency types. Pearson[22] has justly opposed this method as a general solution of the problem of random sampling, but it can be considered as a part of his system when the change of variable is

[21] J. Bertrand, *Calcul des Probabilités*, p. 180, Gauthier Villars, Paris, 1889.
[22] Karl Pearson, *Biometrika*, 4, 169–212, 1905–1906.

also appropriate for other reasons. Now the variation of the bacterial index is actually found to be more nearly normal than is the distribution of the number of bacteria. Indeed Wolman's and Houston's results are strikingly so.

It is therefore of particular interest to bacteriologists to be familar with the properties of that simple type of chance variation which occurs in the variate (X) when the variation in the index (x) is normal, or the law of error. Thus if ($dN \equiv Nydx$) represents the number of variates between (x) and ($x + dx$), normal frequency is defined by

$$y = \frac{1}{\sigma_x \sqrt{2\pi}} \exp\left[-\tfrac{1}{2}\left(\frac{x-\bar{x}}{\sigma_x}\right)^2\right] \tag{26}$$

and the only constant is the standard deviation $\sigma_x \equiv N \Sigma (x - \bar{x})^2$. Placing $\gamma \equiv \exp(c^2 \sigma_x^2)$, where $c \equiv \ln 10$ enters because common logarithms are used, the corresponding X-distribution is given by

$$Y = \frac{1}{c\sigma_x X_m \sqrt{2\pi\gamma}} \exp\left[-\frac{1}{2\sigma_x^2}\left(\log \frac{X}{X_m}\right)^2\right] \tag{27}$$

This may be called *normal geometric variation.* The geometric mean ($\overline{X} = \gamma X_m$) is the *median,* one half the variates being less, one half greater. It has never before been noticed that for small variabilities (V) Pearson's empirical rule

$$\text{Mean} - \text{Mode} = 3\ (\text{Mean} - \text{Median})$$

can be deduced for such variation. For the exact relation $\overline{X}^3 = \overline{X}$ X_m reduces to

$$\overline{X} - X_m = 3\ (1 - \tfrac{1}{2}V^2)\ (\overline{X} - \bar{X}) \tag{28}$$

where ($\overline{X}$) is the arithmetic mean and (X_m) is the mode, or most probable value.

The standard deviation of the index (σ_x), or its equivalent (γ), is the only constant of normal geometric variation. The variability (V) is

$$V \equiv \sigma_x/\overline{X} = \sqrt{\gamma - 1} \tag{29}$$

and Pearson's constant ($\sqrt{\beta_1}$) which Bowley adopts as the skewness (κ) is

$$\kappa \equiv \sqrt{\beta_1} \equiv \mu_3/\sigma_x^3 = V(\gamma + 2) \tag{30}$$

where (σ_x) is the standard deviation and (μ_3) is the third moment about the mean ($\overline{X}$).

Normal geometric variation has a simple theoretical interpretation. It arises when proportional variations are distributed at random without correlation. Equal proportions in excess and defect are therefore equally probable. The fact that this chance distribution gives Pearson's empirical rule suggests that the logarithm could be used to advantage as a variable in many cases of skew variation, and particularly in the field of correlation.[23]

In bacteriology every change in the environment produces its effect upon the whole bacterial population, so that proportional variation seems only natural. Moreover, wherever characters are

TABLE 8

	POTOMAC RIVER		WASHINGTON WATER SUPPLY
	Cedar Point	Giesboro Point	
Number of samples (N)	938	294	916
Variability (V) per cent	160	150	230
Skewness (per cent)	35	50	380
Unit, Bacteria per liter	$\times 10^{-3}$	$\times 10^{-5}$	Turbidity (p.p.m.)
Observed mode (X_m)	10–20	20–30	10–20
Normal geometric mode	8	7	6
Observed median ($X_{\frac{1}{2}}$)	19	43	40
Observed geometric mean ($\overline{X}$)	21	40	51
Normal geometric mean (from $\overline{X}$, σ_x)	18	52	59
Observed arithmetic mean ($\overline{X}$)	34	93	150

discrete magnitudes, where zero practically never occurs, but where very large variates are fairly frequent the skewness is quite generally positive, and then the logarithm is distributed more nearly normally than is the variate itself. But it must not be forgotten that the variation of the bacterial index is only rarely normal within the errors of random sampling. Pearson's first order curve (type III) is usually a better fit even for the index, and in some extreme cases the skewness is even more marked. On the whole, however, it cannot be questioned that experience favors the use of the index for bacterial distributions, that the geometric mean is usually a fairly close approximation to the median number of bacteria, and that the average index is a fair approximation to both the median and the most probable index.

[23] Yule and McEwen have both remarked this advantage. Yule, *Theory of Statistics*, p. 202, 3rd ed. Griffin, London, 1916. G. F. McEwen and E. L. Michael, *Proc. Am. Ac. Arts and Sci.*, 55, no. 2, p. 129, 1919.

The following examples show the time distributions at two points in the Potomac River,[24] and are compared with the variation of turbidity in the Washington water supply,[25] to illustrate the nature of such distributions.

The chief use of a frequency distribution is in predicting the magnitude of deviations to be expected in future sampling. Stein has used for this purpose Tchebycheff's criterion, which states that a deviation from the mean greater than (T) times the standard deviation (σ) occurs less than once in (T^2) times. It is practically useless for normal variation, but is somewhat better for normal geometric variation, as is shown in table 9.

TABLE 9

Frequency of positive deviations exceeding $T\sigma$

T	TCHEBYCHEFF'S CRITERION LESS THAN ONE IN	NORMAL DEVIATION ONE IN	NORMAL GEOMETRIC VARIATION		
			V = 10 per cent one in	V = 50 per cent one in	V = 100 per cent one in
1	2	6	5	3	5
2	8	43	24	9	14
3	18	740	175	21	33
4	32	31,500	1,140	47	68
5	50		26,700	104	136

It is hoped that enough advantages have been demonstrated in the bacterial index to convince bacteriologists of its propriety. We have no doubt that if once used, its practical convenience will lead to its adoption as the standard bacterial index. If bacterial indices are chosen as constituents of any more comprehensive index of water quality,[26] the component indices must be stable or they will have undue and erratic influence upon such a quality index. The standardization of the bacterial index is therefore a necessary preliminary in any more ambitious program.

12. SUMMARY

1. The paper is a statistical study of the advantages of the logarithm of the number of bacteria per liter as a bacterial index.

[24] *U. S. Hygienic Laboratory Bulletin*, no. 104, p. 84, 1916.

[25] W. F. Wells, *Proc. Am. Water Works Assn.*, 353–63, June, 1913.

[26] See discussion of this question by A. Wolman (this JOURNAL, 6, 444–456, 1919).

2. Poisson's "law of small numbers" is applied to the dilution method, assuming the random samples to be independent (uncorrelated).

3. The simplest dilution scale is formed by assigning serial numbers 1, 2, 3, 4, etc., to inoculations containing 100 cc., 10 cc., 1 cc., 0.1 cc., etc. The "dilution positive" is the highest dilution in which bacteria are present.

4. The average dilution positive, with the constant 0.24 added, gives the average bacterial index. The standard error of sampling of a single tube is 0.55, corresponding to a variability in the number of bacteria of 200 per cent.

5. The dilution positive method is shown to be a simple and logical system of weighting the average, the constant correction 0.24 resulting from the dilution interval chosen.

6. When the tests are incomplete, so that in the largest inoculations less than 25 per cent of the tubes are positive, the most probable bacterial index is simply the logarithm of the sum of the percentages positive in dilutions 1, 2, and 3, minus 1.05; or of dilutions 2, 3, 4, minus 0.05, etc. But complete tests are recommended, whenever possible.

7. When plates are counted the fluctuations of sampling are unimportant, being less than 30 per cent for more than 10 colonies per plate. The disadvantage of taking logarithms is more than compensated by the greater stability of the average index, for proportional errors of measurement are larger in the larger variates, which are subject to more dilutions. Significant tendencies can be recognized in the average index with fewer samples than when the average number of bacteria is taken.

8. Bacterial distributions often approach the normal form when the index is used as variable. The geometric mean number of bacteria (the antilogarithm of the average index) is therefore a fair approximation to the median number.

9. Incidentally it is noticed that Pearson's empirical rule: Mean + Mode = 3 (Mean − Median) holds for normal geometric variation.

10. The choice of average, as of observed character, is arbitrary, a matter of convenience. From every point of view the geometric mean number and the average index are the most appropriate expressions for results in bacteriology.

DISCUSSIONS

WATER RATES[1]

The authors evidently had some trouble in classifying output or capacity charge. This capacity charge has been a stumbling block before. The term comes from the electric light business, and, in the electric light business, the capacity charge seems to be an item of vital interest. In the water works business it is not nearly as important. Water takers have very regular habits, and the maximum drafts occur at well determined times, and, within limits, they can be easily met by any properly equipped water works system.

The highest peak load, as Mr. Fenkell has shown from Detroit experience,[2] is only from 50 to 75 per cent above the average. This, of course, is exclusive of fire drafts. Fire drafts are generally large, and the works have to be built to meet them. The ordinary drafts are much less than the fire drafts, and the capacity factor is not really so very important in the water supply business.

It has seemed to me that the cost of service could be classified more helpfully and with much less complication by a slight change in the procedure.

The whole cost of service may be divided into three parts. The first part is the *service cost* and includes all the costs of the connections and meters and bookkeeping and collecting; and this cost for the whole system should equal the sum of the service charges, and should be met by them.

The second part is the *cost of water*. That represents the whole cost of the water up to the point where it goes into the distribution system under pressure. That cost can be figured at so much per thousand gallons and this cost of water forms the first element in the meter schedule.

The third part of the cost is all that remains and this may be called the *cost of distribution*. This cost of distribution includes practically the whole of the cost of the fire service, and whatever receipts there may be for fire service should be credited to this account. The remainder

[1] JOURNAL, September, 1921, page 497.
[2] JOURNAL, November, 1921, page 583.

of the distribution cost must be carried in some way by the meter rates. Some small part of it may be carried into the service charge, a large part may be carried as a loading on the cost of water per thousand gallons, going with all the water sold. But a substantial part of it will be carried by the higher steps of the sliding scale applying to the first quantities of water sold sufficient to cover this element of the cost.

This is a logical thing to do because it costs more per thousand gallons to distribute water to many small takers than to a few large ones. This is the reason for the sliding scale and it appears to be the only reason for the sliding scale that will stand critical examination.

The analysis of the whole problem, in which the capacity factor, borrowed from the electricians, has been given great weight, is interesting as a study, and it appears in the hands of the authors to have led to results that do not differ widely from those reached by the simpler analysis above outlined.

ALLEN HAZEN.[3]

DRINKING WATER AND DISEASE[4]

I have enjoyed thoroughly reading the very interesting article by Dr. H. E. Robertson upon the Relation of Drinking Water to Disease. I hesitate to criticise because of the possibility that our modern methods for purifying water supplies may destroy or eliminate substances which are useful or necessary to the human organism, although there is as yet little if any tangible evidence that such is the case.

The article is purely speculative in nature but contains a very important suggestion, namely, that we should begin to observe whether there may not be other important relationships of drinking water besides those of infectious diseases. A weak point in the article to my mind is the fact that we do not depend upon water to furnish us anything but water. We try to eliminate harmful substances, bacterial or chemical, but for dietary purposes we depend upon changes in the food ration to supply our deficiencies. The source of salts, minerals, or vitamines necessary to the human organism is food rather than water and the remedy for destruction or elimination of these lies in additions to supply food deficiency rather

[3]Consulting Engineer; Hazen, Whipple and Fuller, New York, N. Y.
[4]JOURNAL, January, 1922, page 46.

than tampering with the water. If iodine is deficient in certain water, it is probably only an index that it is probably deficient in the food products of the soil in such areas and this deficiency should be supplied in the food ration independent of water.

I quite agree with Dr. Robertson that some cognizance should be taken of the constituents of our finished product as delivered to consumers and that efforts should be made to determine what effects, if any, such finished products have upon the human organism, due to changes in the constituents effected by the processes of purification.

A. J. McLaughlin.[5]

[5]Assistant Surgeon General, United States Public Health Service, Washington, D. C.

SOCIETY AFFAIRS

NORTH CAROLINA SECTION

The first annual convention of the North Carolina Section was held at Greensboro on December 9 and 10, 1921, at the O. Henry Hotel. The meeting was well attended and enthusiastic. Over fifty water works superintendents from various parts of the state attended the sessions.

The following general program will give some idea of the variety of subjects presented and discussed:

"Filter Plant Operation and Training of Operators," by George F. Catlett. Discussion by L. O. Craig, George D. Norcomb, W. E. Vest, H. L. Shaner, Thorndike Saville, and J. L. Ludlow.

In the evening of December 9, the meeting was addressed by the Mayor of Greensboro, by the president of the Section, Colonel Ludlow, and by Dr. W. S. Rankin, Secretary of the North Carolina State Board of Health.

On December 10, these papers were presented:

"Problems of the Interconnection of Water Supplies for Fire Protection," by Thorndike Saville.

"Water Supply and Fire Protection," by S. B. Brockwell of the State Insurance Department.

"Public Utility Accounting in Small Towns," by W. J. Root.

"Maintenance Problems," a topical discussion led by M. M. Boyles.

Secretary Diven addressed the Section at a luncheon. He announced that this Section would win undoubtedly the membership cup for the best showing in increased membership during this year.

The officers for the coming year are: Chairman, J. L. Ludlow, Winston-Salem, N. C.; vice-president, J. C. Michie, Durham, N. C.; secretary, Thorndike Saville, Chapel Hill, North Carolina.

The next annual convention will be held in Gastonia, North Carolina.

NEW YORK SECTION

The March meeting of the New York Section was opened at Brown's Chop House, New York City, on March 2, 1922. The

attendance was one of the largest of any of the recent meetings. While lunch was being served, the members were entertained by Harry Armstrong, a professional singer.

Beekman C. Little, ex-president of the American Water Works Association, read a paper on men, methods, and materials in the water works field, entitled "Some Water Works Supply Men I Have Met." The paper was discussed by David Decrow, D. W. French, John M. Diven, R. K. Blanchard and Dennis P. O'Brien.

Frank T. Kemble was elected to fill a vacancy on the board of governors to replace George A. Johnson. Three new members and one associate were elected to the section.

The board of governors will hold their organization meeting at the National Convention in Philadelphia. The next meeting of the section will be called in the fall.

NOTICE

The Committee on Industrial Wastes in Relation to Water Supply is seeking information relative to water supplies in this country affected by industrial wastes, the nature and effect of the objectionable substances, remedies applied and the laws and court decisions relating to the matter. Will those members of the Association having such information kindly furnish the same to the Chairman, Almon L. Fales, 14 Beacon Street, Boston, Mass.?

CORRECTION

The paper entitled "A Facultative Spore-Forming Lactose-Fermenting Organism from Iowa Surface Waters" (JOURNAL, March, 1922, page 330) is a contribution from the Department of Bacteriology and Pathology of the State University of Iowa.

NOTICE FOR ABSTRACTS

In order to facilitate the preparation of the abstracts, it is requested that members forward all city and department water system reports for review to H. E. Jordan, Indianapolis Water Co., Indianapolis, Ind.

ABSTRACTS OF WATER WORKS LITERATURE

FRANK HANNAN

Key: American Journal of Public Health, **12:** 1, 16, January, 1922. The figure 12 refers to the volume, 1 to the number of the issue, and 16 to the page of the Journal.

Rules and Regulations. Ohio State Board of Health, revised and adopted July 19, 1921. Of interest to the engineer is the chapter on sanitary engineering, pages 37 to 55. This chapter deals with waste disposal, protection of wells, the requirements of the Board in the matter of sewage treatment plants, garbage disposal plants, water supply and water purification plants, and standards of purification. Reports and plans of proposed water works must be submitted to the Board for approval and the character of the reports and drawings required are set forth in detail. In passing, it is interesting to note the following paragraph on page 52: "If for the purpose of fire protection it is necessary to provide pipes by which partly treated water or raw water can be turned into the mains, they shall have valves upon them of such a character that they may be properly sealed by the State Board of Health or local Board of Health." This appears to afford opportunity for potentially dangerous water to be discharged at times into the mains, as the sealing of the valves affords no assurance that the valves will not be opened and unsafe water supply sent to the consumer.—*E. S. Chase.*

Engineering Bulletin No. 1. Maryland State Department of Health, **1:** 1, October 1, 1921. A collection of papers upon various phases of water supply prepared by members of the engineering force of the Maryland State Department of Health. These papers have already been published in various technical journals. Table of contents as follows:

Introductory Statement.

A Plan for Meeting Water Supply and Sewerage Costs, by Robert B. Morse and Abel Wolman

A Preliminary Analysis of the Degree and Nature of Bacterial Removal in Filtration Plants, by Abel Wolman

Chlorine Absorption and the Chlorination of Water, by Abel Wolman and Linn H. Enslow

Water Chlorination Control by the Absorption Method, by Abel Wolman.

Index Numbers and Scoring of Water Supplies, Parts 1 and 2, by Abel Wolman.

The Statistical Method in Problems of Water Supply Quality, by Abel Wolman.

Sanitary Effect of Water Storage in Open Reservoirs, by Abel Wolman and S. T. Powell.

The Surface Shrinkage of Rapid Filter Sand Beds, by Abel Wolman and S. T. Powell.

Residual Aluminum Compounds in Water Filter Effluents, by Abel Wolman and Frank Hannan.

Further Observations on pH in Natural Waters, by Abel Wolman and Frank Hannan.

—*E. S. Chase.*

Health Laws and Regulations. Minnesota State Board of Health, November 1, 1921. Laws relating to water supply are given on page 22. The laws make it a felony knowingly to permit water works appliances to become in such condition as to impair the healthfulness of water supplies. Regulations of the Board of Health regarding water supply are given on page 49. Plans for new water works and modifications of old systems must be approved by the Board. Cross connections between safe and unsafe supplies are prohibited. Contracts between municipalities and private water companies must be approved by the State Board of Health in so far as the sanitary quality is concerned.—*E. S. Chase.*

State Department of Health of New Jersey. Annual report for the year ending June 30, 1921. Report of the Bureau of Engineering page 87, describes the organization and work of the Bureau. In connection with an investigation of the significance of B. Welchii, it is the opinion of the Bureau that the presence of this organism has no particular sanitary significance in judging quality of water supply. It is also the opinion of the Bureau that the chlorination of water supplies is a temporary measure only and under certain circumstances additional protection by prolonged storage or filtration is required. Only a small proportion of New Jersey is now supplied with untreated water. Of the urban population 46 per cent is now provided with filtered water, 31 per cent with chlorinated water and 1.5 per cent receives unfiltered surface water. It is interesting to note that no outbreak of typhoid fever occurred during the year, as a result of infected public water supply. Valuable data upon water treatment plants in New Jersey is given in tabular form, together with the results of analyses. In the report of the State Laboratory of Hygiene, the results of a B. Welchii investigation (page 128) are summarized. Some 26 water supplies were examined serving 1,600,000 consumers, and of these supplies 19, serving 800,000 consumers, showed B. Welchii present in 50 cc. samples, but in amounts not exceeding 4 per 50 cc. B. Welchii were also found in milk supplies.—*E. S. Chase.*

Index to Bulletins 1 to 16 of the Division of the State Water Survey. Department of Registration and Education, Urbana, Illinois, 1921.—*E. S. Chase.*

The Influence of Sanitary Engineering on Public Health. George W. Fuller. American Journal of Public Health, 12: 1, 16, January, 1922. A general discussion of the accomplishments of the engineers along sanitary lines in the field of water supply, water purification, sewage, sewage disposal, controlling of streams and collection and disposal of solid wastes. In the

matter of water supply and water purification, Mr. Fuller briefly reviews the historical development of water purification in America, and points out that as a result of water purification a marked reduction in typhoid fever death rates has been brought about, as shown in a table of typhoid fever death rates for the principal large American cities since 1880. The necessity for proper supervision and laboratory control of purification plants is pointed out. The value of chlorination is also referred to, but the danger of placing too great reliance on chlorination alone is emphasized.—*E. S. Chase.*

The Proper Size of Sand for Rapid Sand Filters. W. H. Dittoe, American Journal of Public Health, 12: 1, 44, January, 1922. Paper deals with rapid sand filters having sand of various effective sizes. In passing upon the result of operation, the Ohio State Department of Health has concluded that an effluent of disinfected water should show the absence of gas formation in 10-cc. samples, that the purification plant should produce a final product of this requirement under the worst conditions of raw water, and that the plant should be so operated that each part of the process will produce its proper share of the work. Disinfection to be considered as a factor of safety only. An approximate standard for filtered water, but without disinfection, is that not more than 20 per cent of the 10 cc. samples should show gas formation. A study of the efficiencies of Ohio plants showed that those plants having coarse filter sand, effective size 0.6 mm. or more were not producing uniformly satisfactory results. While on the other hand it was found that plants having fine filter sand, effective size 0.45 mm. or less, were producing with regularity a filtered water of high degree of purification. There were no important differences in the kind of raw water, plant design, method and control of operation, except the sand used as filtering medium. As a result of the particular studies the following tentative specifications were adopted: sand shall have an effective size between the limits of 0.35 mm. and 0.42 mm., and a uniformity coefficient not greater than 1.8. Preference will be given to sand having an effective size of 0.37 mm. and a uniformity coefficient not exceeding 1.6, all particles of which are finer than 1 mm. Objections to the use of fine sand, such as increase in loss of head and percentage of wash water, loss of sand through underdrainage or strainer system and in the wash water, together with the increased cost for sand of the specifications above set forth, are met. Experience shows that the fine sand does not involve an increase of wash water, nor that there is any material reduction in the volume of the sand. The cost of the sand in meeting the more rigid requirements is somewhat greater, but Mr. Dittoe claims that this increased cost is small in comparison with the total cost of the purification plant, and is offset by the higher efficiencies obtainable. This paper is discussed by Alexander Potter, Consulting Engineer. Mr. Potter raises a question as to whether the State in making requirements which must be met by the engineer and the contractor should not guarantee results. This suggestion appears similar to the demand from certain quarters in Massachusetts that the state shall guarantee savings bank deposits. Mr. Potter also points out the increased cost to contractors in meeting the specifications. This objection to the standard proposed does not appear to be serious if the contractor appreciates the importance of secur-

ing proper sand in the first place, as he is then in a position to protect himself when he makes his original bid. It seems quite general for contractors to fail to appreciate the importance of proper filter medium and any removal of safeguards in the matter of specifications for sand appears unwise.—*E. S. Chase.*

How a Water Company Co-operates with Water Users. Eng. & Cont., **57**: 6, 127, February 8, 1922. A reprint of a folder issued to water consumers by the Terre Haute Water Works Company, Terre Haute, Indiana, Dow Gwinn, President and Manager. This pamphlet instructs the householder in matters relative to the shutting off of water, the care of sill cocks, the thawing of frozen pipes, and the care of water closets, with the object of preventing water waste. An example of educational publicity by a progressive water works company.—*E. S. Chase.*

Methods of Blasting Drilled Wells to Increase Flow of Water. Eng. & Cont., **57**: 6, 127, February 8, 1922. Abstract of an article by S. R. Russell, in the November–December, 1921, issue of the DuPont Magazine. The desirability of blasting drilled wells will depend upon the character of strata penetrated, and the quantity of water probably contained therein. In sand strata blasting has practically no effect, as the material will settle back around the casing. In water bearing rock, however, passageways into the surrounding rock may be opened up and the cross sections of the boring enlarged, thereby increasing the yield. Methods of blasting are derived from oil well shooting. The explosive is placed and fired at the water bearing stratum. A heavy charge of quick, powerful explosive is required. The article describes in some detail the quantity of charge, kind of explosives to be used, the method of placing and exploding the cartridges and means for prevention of collapse of the casing.—*E. S. Chase.*

The Proper Charges for Fire Protection. HENRY L. GRAY. Eng. & Cont., **57**: 6, 134, February 8, 1922. A study and analysis of water works charges and earnings prepared by Gray in 1921 for the Pacific Power & Light Company relative to its water plant in Yakima, Washington. This paper discusses the apportionment of water systems between fire protection and other services. Three methods are referred to: (1) Residue plant; (2) Comparative plant; (3) Maximum demand. The author advocates the third method which is based essentially upon the relation of the maximum demand for fire service to the maximum demand for all other services. By the maximum demand method the author estimated that a fair charge to the City of Yakima for fire protection should be $33,883 yearly as compared with $7399 actually paid in 1920 on the hydrant rental basis. The paper concludes with a table showing the allocation by various commissions of plant value and gross earnings required for fire service in some 47 municipalities.—*E. S. Chase.*

Experiments Show Measurement of Valve Loss Dependent on Piezometer Location. Eng. & Cont., **57**: 6, 137, February 8, 1922. Abstract of article from the Wisconsin Engineer (January, 1922) University of Wisconsin. Ex-

periments indicated that the loss of head due to flow through valves should be obtained by piezometers located at least fifteen or twenty diameters below the valve. The disturbance caused by the water passing through the valve will affect results obtained with piezometers set nearer the valve.—*E. S. Chase.*

Population 1920. U. S. Bureau of Census, 1921. Report of the 14th decennial census which presents statistics showing the number and distribution of the population of the United States by states, counties, incorporated places and other minor civil divisions.—*E. S. Chase.*

Siphon Pipes of the Catskill Aqueduct. Municipal Engineers Journal, Third Quarterly Issue, 1921, page 93. A notice of the awarding of three contracts, total $6,252,788 for the construction of two pipes in each of the 14-foot steel pipe siphons along the line of the Catskill Aqueduct. One pipe is now in place and the additional pipes will be capable of carrying the capacity of the aqueduct which is in excess of 500,000,000 gallons daily. The new pipes will be of riveted steel, 7 feet 4 inches to 11 feet 3 inches nominal inside diameter with plates $\frac{7}{16}$ to $\frac{9}{16}$ inches thick, lined with Portland cement mortar, enveloped with concrete and covered with earth and rock.—*E. S. Chase.*

Proc. American Society for Testing Materials **21**: 1921. Compilation of committee reports, tentative standards submitted or revised at 1921 annual meeting, tentative revisions of standards and technical papers.—*E. S. Chase.*

Determination of pH in Water by Means of Indicators without Buffer Solutions. L. MICHAELIS. Zeitsch. Untersuch. Nahr. Genussm., **42**: 75–80, 1921. (cf., The Analyst, February, 1922.) Into each of six tall test glasses are put 40 cc. of 0.02 N NaOH freshly diluted from N solution, and 0.25, 0.29, 0.33, 0.38, 0.45, 0.50 cc. of a standard solution of m-nitrophenol (0.3 gm. in 300 cc. diluted 1:10 for use). To 40 cc. of the water to be tested is added from a graduated pipette a sufficient quantity of the indicator solution to match the color of one of the standard alkali tubes. Let F denote the volume of the indicator solution in the particular standard color tube which is matched, divided by that added to the water tube, then pH is calculated from the equation $\text{pH} = P_K + S + g + \phi$, where P_K is the constant for the indicator (= 8.33 for m-nitrophenol), s is the salt correction (for sea-water = 0.16, and for fresh water a negligible quantity), g is the temperature correction, which is negligible at ordinary temperatures, and $\phi = \log \frac{1-F}{F}$. Curves are given, which show the last named quantity at a glance.—*A. Wolman.*

Air-Lift System. J. S. OWENS. Canadian Engineer, **42**: 256, February 21, 1922. Advantages of this system of pumping are discussed and an explanation given of how the low efficiencies often encountered may be avoided.—*R. E. Thompson.*

The Rate of Solution of Oxygen in Water. H. G. Becker. Sci. Proc. Roy. Dublin Soc., **16**: 334–44 (1921). From Chem. Absts., **16**: 363, February 10, 1922. Co-worker of Adeney describes apparatus for determining rate of solution of oxygen in water. Rate of solution was found graphically to be a linear function of the rate of stirring, surface area remaining constant. Very gentle stirring of the under layers of the liquid was found to increase the rate of solution as much as twenty-fold, as compared with stationary water.—*R. E. Thompson.*

The Coagulation of Colloids by Electrolytes. L. Michaelis and C. Timenez-diaz. Kolloid-Z, **29**: 184–90 (1921). From Chem. Abst., **16**: 370, February 10, 1922. It is pointed out that no theory of the coagulation of colloids by electrolytes can satisfactorly explain all results unless the influence of the H^+ and OH^- ions is taken into account. For instance it was found in experiments on Congo rubin with various concentrations of Na^+ and K^+ that these two ions have the same effect. The coagulating power is a function of the H^+ and alkali ion concentration. The anions in this case were without influence. The authors develop a law which they call the "law of ionic synergism."—*R. E. Thompson.*

The Preparation of Carbonate-Free Alkali. I. M. Kolthoff. Pharm. Weekblad, **58**: 1413–7 (1921). From Chem. Abst., **16**: 393, February 10, 1922. An approximately 1.1 N solution is prepared from commercial sodium hydroxide and 50 cc. milk of lime per liter added. After standing overnight the supernatant liquid is syphoned off, titrated and diluted to 0.1 *N* with carbon dioxide-free water. The calcium content does not exceed 1 to 2 mgm. per liter, which is negligible in most analytical procedures.—*R. E. Thompson.*

Uses of Stainless Steel. Anon. Engineering, **112**: 592–594 (1921). From Chem. Abst., **16**: 401, February 10, 1922. Experiments show that stainless steel is superior to phosphor-bronze, nickel-bronze, brass and mild steel for turbine blading. Examination of a turbine with blades containing 5 per cent Ni alongside stainless steel blades (13.4 per cent Cr and 0.30 per cent C), after being in operation 3471 hours showed the stainless steel to be unaffected while the Ni steel blades were materially roughened at the inlet edges and had also suffered corrosion. Stainless steel can be used to advantage for rams for hydraulic pumps and other purposes.—*R. E. Thompson.*

Structural Steel Paints. J. S. Coye. Iowa Eng. Exper. Sta., Bull 54, 68 pp. (1919). From Chem. Abst., **16**: 503, February 10, 1922. Zinc chromate is the best pigment and may be used to advantage with other ingredients such as Fe oxide. Coal-tar paints are worthless as a steel coating. Gypsum and whiting are harmful when in excess of 5 per cent of the paint pigment.—*R. E. Thompson.*

Adsorption. A. P. Mathews. Physiol. Rev., **1**: 553–97 (1921). From Chem. Abst. **16**: 425, February 10, 1922. Adsorption is considered to be a chemical rather than a physical phenomenon. The forces of cohesion and

chemical affinity differ in several particulars. Cohesion varies inversely as the fourth power of the distance, chemical attraction probably inversely as the square. Included in the discussion are surface tension and the charge on colloidal particles which is stated to be due, not to adsorbed ions, but to chemical additions and subsequent ionization of the compound.—*R. E. Thompson.*

Kutter's Formula Simplified. H. E. BABBITT. Eng. & Cont., 57: 6, 128, February 8, 1922. The writer claims that "in ordinary problems met in the design of sewers, drainage ditches and other small open channels, the discrepancy between the value of V as found by Kutter's formula"

$$V = \frac{\frac{1.81}{N} + 41.67 + \frac{0.0028}{S}}{1 + \frac{N}{\sqrt{R}}\left(41.67 + \frac{0.0028}{S}\right)} \sqrt{RS} \qquad (1)$$

in which V = Velocity of flow in feet per second
N = Roughness coefficient of material of conduit
R = Hydraulic radius, in feet
S = Slope of hydraulic gradient

and the value of V omitting the term $\frac{0.0028}{s}$ is negligible. If this term is omitted this formula can be written as

$$V = \frac{(1.81 + 41.67\,N)\sqrt{R}}{N\sqrt{R} + 41.67\,N^2} \sqrt{RS} \qquad (2)$$

A table is given showing values of C and the percent error in same as determined by Kutter's original and the modified formula, for S (slope) 0.00005; 0.0001; 0.001; 0.0 (N) = 0.010 and 0.020; and hydraulic radii of 0.1; 1; 3.28; 4 and 8 feet.—*A. E. Gorman (courtesy I. W. Mendelsohn.)*

History of Water Purification. GEO. C. WHIPPLE, Proc. A. S. C. E., 47: 10, 654, December, 1921. The history of water purification in the United States is intimately connected with the general movement to improve sanitation as well as with the rise of modern science. The English public health system dates from 1848. The Massachusetts State Board of Health was established in 1869. The American Association of Public Health was founded in 1872. It was during the last half of the 19th Century that modern science began its remarkable development. The rise of the science of bacteriology caused the modern development of this greatest of the sanitary arts—the art of water purification. Kirkwood's report for St. Louis, Mo., in 1866, on filtration practice in England and Germany, may be said to mark the beginning of the history of water purification in America. His plan, however, was not adopted by St. Louis. Other filters, however, were built as a result of his report, notably the filter at Poughkeepsie, N. Y., constructed in 1873. In 1887 the Massachusetts State Board of Health established an experiment sta-

tion at Lawrence and the purification of water was studied from all possible angles. In 1893 a sand filter without a roof was put into operation for the City of Lawrence. In 1884 Alpheus Hyatt obtained a patent on the use of sulphate of alumina as a coagulant and in the same year a mechanical filter using such a coagulant was built at Somerville, N. J. Albert R. Leeds was the real inventor of this process. In 1883 Charles Hermany conducted experiments at Louisville, Ky., and again from 1895 to 1897 he studied the problem of filtration for the Louisville Water Company. The principles thus established have served as the basis of the mechanical filters. The experiments at Lawrence and Louisville demonstrated the fact that, although slow sand filtration can be used successfully with a relatively clear water, coagulation must accompany filtration in the case of muddy water. The Albany covered filter built in 1899 has served in many ways as a model for the sand filters. The first important mechanical filter to be constructed along modern lines was that of the East Jersey Water Company in 1902. It was, therefore, just about the beginning of the 20th Century when water purification in the United States really began to advance as a practical measure. In 1870 practically no filtered water was in use in this country. In 1921 more than one-third of the people living in cities which contained 2500 or more inhabitants are using filtered water. The number of filters is not far from 800. (There are still some places where grossly polluted water is being distributed to the people.) Consumers are now thinking less about the dangers of their water supplies, that is, they are seeking refinements. The economies of filter operation can now be studied more carefully than was possible 25 years ago and this is a phase of the subject which is likely to receive increasing attention. Engineers now are interested in knowing what the filter actually does and the analyses must serve as a test of the filter operator as well as the filter itself. At the moment, a new impetus is being given water purification by the use of hydrogen ion concentration. Some more careful measure of the effect of water on the health of the community is urgently needed to supplement the b. coli test.—*E. E. Bankson.*

Recent Developments in Water Filtration. ALLEN HAZEN. Proc. A. S. C. E., 47: 10, 660, December, 1921. Treatment of water so as to purify it adequately without making it aggressive is one of the most difficult problems at present. An aggressive water attacks and tuberculates the pipes. Quiet waters do not have this tendency to attack metal. This deposit is a dirty mud which moves forward with disturbed flow and makes the water dirty and disagreeable. Alkalinity and carbonic acid really have something to do with aggressive qualities, but all the conditions cannot be accounted for by them. A great deal is known in a practical way as to which waters are aggressive. The waters of the Great Lakes are almost always quiet. In the Mississippi Valley, from the Alleghanies to the Rockies, the surface waters can be handled so that the resulting products will be reasonably quiet. Soft waters are frequent nearer the coasts. These waters are much more apt to be aggressive, and it is with them that the greatest practical difficulties have been met. The question of arranging all the treatments of public water supplies so as to keep them always quiet is one of the most interesting and important aspects of water purification at the present time.—*E. E. Bankson.*

Interference with Filtration by Wastes from By-Product Coke Ovens and Gas-Works. C. A. EMERSON, JR. Proc. A. S. C. E., 47: 10, 662, December, 1921. Discharge of liquid wastes from by-product coke ovens and commercial gas plants into stream and lakes becomes a matter of grave concern to many cities, due to the disagreeable tastes and odors which these wastes impart to the water. Wastes from the separators of by-product coke ovens, together with the sludge, impart a characteristic taste to river water. This taste may persist for days and may be noticeable in the effluent from filtration plants. Application of chlorine seems to accentuate these taste-producing characteristics. Fortunately, the remedy for this pollution lies within the works, and consists simply of using the wastes for quenching or cooling the flowing coke taken from the ovens. Interference with water supplies by the wastes from plants producing water gas has been noticeable and the taste-producing characteristics are accentuated by chlorination of the drinking water. In this case, again, a remedy can be developed at the gas works. Installation of settling and skimming basins for removal of the greater portions of the heavier tars and the light floating oils, with the effluent for re-use in the "gas scrubbers," will reduce the volume of wastes reaching the stream to a small fraction of that which occurred before and the company recovers marketable materials.—*E. E. Bankson.*

Recent Progress in the Reduction of the Typhoid Death Rate and its Significance. C.-E. A. WINSLOW. Proc. A. S. C. E., 47: 10, 664, December, 1921. For ten years to 1908 each of thirty-five cities had average death rate of more than fifteen, and up to 116.9 per 100,000. In the last three years, however, only one city of the same thirty-five has had rates of more than fifteen, only six had rates of more than ten, while more than one-third have had rates below five per 100,000 and this is general throughout the United States. The water works engineer, however, should not receive all the credit because other powerful forces have also been at work.—*E. E. Bankson.*

The Effect of Improvements in Water Supplies on Typhoid Death Rate in New York State. C. A. HOLMQUIST. Proc. A. S. C. E., 47: 10, 667, December, 1921. In 1901, a State Department of Health was created. In 1906 the Division of Sanitary Engineering was established. Before 1906, the average death rate from typhoid fever for the whole State was 23.4. Since 1906, the average rate has been 9.4, until in 1920 a remarkably low level of 3.5 was reached. Although other factors have had some effect, the decrease has been due largely to improvements in water supplies. Several cases are cited to show that a decided drop in the typhoid fever death rate occurred immediately after the construction of the filtration plants.—*E. E. Bankson.*

Purification of Soft Colored Waters. R. S. WESTON. Proc. A. S. C. E., 47: 10, 670, December, 1921. A drinking water should have an *average* color of not more than 10 parts per million and not over 15 maximum. It is most often impracticable to store waters long enough to decolorize them sufficiently and, for this reason, many stored colored waters are filtered. Most of the color in water is in the form of a colloidal suspension. These colloidal particles are

not all alike. They possess electrical properties, usually negative, and will coagulate with aluminum hydrate, but some are positive and will not so respond. A slow sand filter is usually unable to remove more than one-fifth of the color from a stored water. The mechanical filter, per se, is an efficient device, and the remedy lies in better chemical treatment. This will require much investigation and many trials. At the present time, sulphate of alumina is added until coagulation takes place, and, in most cases, soda is added to maintain an alkalinity of at least 7 parts per million. Frequently, this method fails or the treated water may corrode the distribution system. Many facts are known, but the principles on which they are based are not yet clear. The problem, therefore, is to substitute a more accurate analysis of color and a more proper dosage with chemicals.—*E. E. Bankson.*

The Operation of Reservoirs for Water Supply. SAMUEL A. GREELEY. Proc. A. S. C. E., **47**: 10, 674, December, 1921. The principal considerations are the use of reservoirs other than for water supply purposes and their maintenance for water supply purposes. The first includes the regulation of the reservoir for bathing, boating, picnicking, etc., as affecting the safe load on water filtration plants. The second includes operations for maintenance of the reservior such as draining and clearing the banks, protection, handling of silt, control of fish life and the like. Some method of patrol is almost always undertaken. A number of rules governing the use of reservoirs have been suggested. The aim of these rules is to prevent the use of the reservoir for bathing, fishing, etc., or to permit some boating, etc., under regulation. Practice indicates that bathing *should not* be permitted with unfiltered supplies and the tendency is against boating, etc. For filtered supplies the use of reservoirs for such purposes appears to be increasing under careful sanitary patrol.—*E. E. Bankson.*

Construction Progress on the Hetch Hetchy Water Supply of San Francisco, California. M. M. O'SHAUGHNESSY. Proc. A. S. C. E., **48**: 2, 147, February, 1922. The Hetch Hetchy water supply project is to supply the Metropolitan Water District 400,000,000 gallons of water daily and to produce 200,000 hydro-electric horse power from the Tuolumne River and tributaries, in the Sierra Nevada Mountains, more than 150 miles from San Francisco on the aqueduct line. The Hetch Hetchy Dam is to be built now to about three-fourths of its ultimate height and thus develop about 60 per cent of the ultimate reservoir capacity. The watershed area covers 652 square miles. Its elevation ranges from 3500′ to 13,090′ and the Congressional grant fixes sanitary regulations. Reservoirs—Hetch Hetchy, elevation, now 3720, future 3800, total capacity 113,500,000,000 gallons. Contract for initial dam—1919 at $5,447,792. Lake Eleanor, elevation, now 4660, future 4715, ultimate capacity 54,000,000,000 gallons. Cherry Valley and other reservoirs later. The Priest Regulating Reservoir, elevation, 2170, capacity—2 days flow of the aqueduct or 800,000,000 gallons. Connection to the Spring Valley System at Crystal Springs reservoir—capacity now 22,000,000,000 gallons, ultimate capacity 50,000,000,000 gallons at elevation 325. Amazon receiving and distributing reservoir, at San Francisco, capacity about 300,000,000 gallons, elevation 248. Hydro-

electric power plants—(at power drops) below Lake Eleanor, Hetch Hetchy and Priest Reservoirs. Contract for constructing the aqueduct tunnel from Early Intake to Priest Reservoir was awarded on the cost-plus-fee basis and the men are working under a bonus system. All expenditures to the present time total about $14,000,000.—*E. E. Bankson.*

The Vertical Triple-Expansion Pumping Engine. A Study of Installations at Cleveland, Ohio, During the Past Sixty-five Years. L. A. QUAYLE AND E. H. BROWN. Mechanical Engineering, **44**: 3, 155, March, 1922. From the standpoint of depreciation Cornish Engine No. 2 was in operation a total of forty-nine years. The Cornish boilers were in operation for 33 years until dismantled because of obsolescence. The effect of increase in steam pressure from 22 pounds in 1856 to 210 pounds today, with improvements in boiler and stoker efficiencies and changes in pumping engine design, has increased the duty from 37,000,000 foot-pounds per 100 pounds of coal in 1856 to 127 in 1920 (without economizers), and the equivalent pounds of coal per kilowatt hour was decreased from 7.5 in 1856 to 2.1 in 1920. The authors' investigation leads them to believe that the Division Avenue station contains at least one and possibly four engines whose duty record and thermal efficiency have never been equaled by any other steam-driven pumping engine, namely 211,000,000 foot-pounds of work per 1000 pounds of steam used and 24.3 per cent thermal efficiency. It is instructive to compare the thermal efficiency (including auxiliaries) of 24.3 per cent obtained on the 1400-hp. vertical triple-expansion pumping engine with 24.8 per cent, the maximum thermal efficiency (excluding auxiliaries) of the Interborough Rapid Transit 45,000-hp. cross-compound turbo-generator; with 24.1 per cent, the maximum thermal efficiency obtained by any one of four 40,000,000 gallons-per-day low-head 300-hp. Humphrey gas pumps at Chingford, England; and also with the 24.1 per cent thermal efficiency obtained on a 1500-hp. natural-gas-engine generating unit of the American Locomotive Company at Alleghany, Pennsylvania, as it shows that these four distinctly different types of units have all reached a point of development at about the same time at which they give practically the same thermal efficiency. This would seem to indicate that any large improvement in the future of any one type must call for a radical departure from the present trend of development.—*E. E. Bankson.*

A Brief on Depreciation. The American Gas Association (130 East 15th Street, New York City) announces in its Bulletin, that it has for distribution to those interested a brief on depreciation charges of Railroads and Public Utilities, submitted to the I.C.C., on behalf of the Consolidated Gas Company of New York and its affiliated companies, by Robert A. Carter, Chairman of the Committee on Rate Fundamentals of the American Gas Association and William L. Ransom, of the New York Bar and counsel for the company in its recent rate litigation. The brief challenges accounting methods of the I.C.C. as to depreciation reserves, and, incidentally, rulings of various state commissions. It contains an exhaustive discussion of the subject which is based on first hand knowledge, rather than on opinions formulated in previous opinions of text writers and public service commissions. It contains also an analysis of the most recent judicial opinions.—*Robert E. Livingston.*

Dilution in the Treatment of Sewage. PETER GILLESPIE. Canadian Engineer, 42: 8,254, February 21, 1922. Originally presented at the Peterboro section of the Engineering Institute of Canada. Author advocates the dilution of sewage effluents, prior to their discharge into bodies of water from which public water supplies are drawn. It is stated that a million gallons of average American sewage requires for its oxidation about 1000 pounds of oxygen. When the oxygen content falls below 70 per cent of saturation, major fish life disappears and when below 30 per cent of saturation is reached, a condition approaching a nuisance, especially in the hot weather, is the result. The self purifying capacity of large bodies of water is shown in that, while the pollution of Lake Ontario at the mouth of the Niagara River is very great, at a distance of 18 miles lakeward from this point, it disappears altogether, judged by the non-occurrence there of the colon bacillus. Five principles are stated as indicating the trend of practice today in the art of sewage treatment:

1. Streams are at once the drainage channels and sources of public water supply of a country.
2. No sewage should be discharged into a stream without some measure of treatment. No public water supply should be taken out without some measure of treatment.
3. Complete purification of sewage is less effective and more costly than a partial purification of the sewage followed by a purification of all water supplies.
4. A wise policy in the design of a plant anticipates the growth of the future and provides for it.
5. Dilution is one of the oldest as well as the most modern of methods.—*Norman J. Howard.*

Corrosion of a Producer-Gas Cooling System. LLOYD E. JACKSON. Chemical and Metallurgical Engineering, 26: 60, January 11, 1922. Water of high acidity containing dissolved oxygen and coke dust corroded pipes of cooling system rapidly. Reduction of acidity to where it was alkaline to methyl orange by lime, and reduction of dissolved oxygen by steel turnings, greatly reduced corrosion.—*John R. Baylis.*

Corrosion of Underground Pipes. Chemical and Metallurgical Engineering, 26: 70, January 11, 1922. Bureau of Standards has undertaken an extensive investigation of the corrosive action of soils on gas and water pipes. Forty locations representing different kinds of soils have been selected and every kind of iron and steel pipe in commercial use will be buried. Corrosion will be determined from time to time. Investigation will probably continue over a period of ten years.—*John R. Baylis.*

Results Achieved by the Corrosion Committee, British Institute of Metals. ERNEST E. THUM. Chemical and Metallurgical Engineering, 26: 301, February 15, 1922. Extensive investigations to determine cause of failure of brass condenser tubes in marine service were made. Comparison of a twenty-year old tube with one that failed in less than twenty months, shows that the nature of the film first formed has a determining influence on the corrosion taking

place. When cast zinc is suspended in distilled water containing acids which pit, hydrogen appears to be evolved in the pits and not at some distant cathode. Experiments with gas-free water seem to show that oxygen is an essential and CO_2 an accelerator of corrosion. Action of distilled water on electrolytic copper here again shows that corrosion largely depends on the first-acquired film. The committee concludes that pitting of brass in sea water is due to a deposit of some sort, and the location of pits a matter of chance. Coke particles, clinkers, sand, glass, flakes of ferric hydrate, or a piece of string may be the cause. The remedy is to prevent the adherence of deposits.—*John R. Baylis.*

Chemical Reactions on Surfaces. IRVING LANGMUIR. Trans. Faraday Soc. (adv. proof), 1921. From Chem. Abst., **16**: 7–8, January 10, 1922. A detailed discussion of surface reactions including the mechanism of adsorption, which is considered to be the time lag between condensation and re-evaporation.—*R. E. Thompson.*

An Electrolytic Method for the Prevention of Boiler Scale. J. SARRAZIN. Z. Dampfkessel u. Masch.; Elektrotechn. Z. 42, 1207 (1921). From Chem. Abst., **16**: 26, January 10, 1922. A piece of flat wrought iron was suspended in the feed water container and a current at 10 volts and 7 amperes applied, making the piece of iron the anode and the boiler plate the cathode. The formation of scale was prevented, owing probably to the evolution of hydrogen on the inner surface of the boiler plate and the calcium sulphate was deposited as a sludge in the bottom of the boiler.—*R. E. Thompson.*

The Water of Crystallization of Permutite. GÜNTHER-SCHULZE. Phys. Techn. Reichsanstalt, Berlin. Z. Electrochem. 27, 402–406 (1921). From Chem. Abst., **16**: 32, January 10, 1922. The influence of the water of crystallization on the behavior of permutite is discussed, and it is pointed out that a much greater time is required for the establishment of the partition equilibrium with an ignited permutite, owing to the loss of its great porosity on ignition.—*R. E. Thompson.*

The Determination of Alkalinity in Culture Media. L. MICHAELIS. Z. Immunität. 32, 194–203 (1921). From Chem. Abst., **16**: 111, January 10, 1922. m-nitrophenol (0.3 gm. in 100 cc. distilled water) is used as an indicator for determining the H-ion concentration of culture media. The color change is from colorless to yellow.—*R. E. Thompson.*

The Fundamental Laws of Filtration. D. R. SPERRY. J. Ind. Eng. Chem. 13, 990–992 (1921). From Chem. Abst., **16**: 130, January 10, 1922. The relationship between flow of liquid, pressure, time, rate of deposition, resistance, per cent of solids, and resistance of filter base, are expressed in formulas previously developed. (Chem. Abst., 10, 2784).—*R. E. Thompson.*

Protective Covering for Steel Pipe. L. M. KLAUBER. Gas Age-Record, 48, 478–484, 514–516 (1921). From Chem. Abst., **16**: 131, January 10, 1922. Cor-

rosion of pipes laid in acid or alkaline soils is prevented by a covering consisting of asphalt, asbestos felt, and burlap. The cost ranges from $2.04 to $6.78 per 100 feet for ¾-inch and 4-inch pipe respectively, the life of the covering varying from 8 to 15 years, depending on the nature of the soil. This covering is also effective in preventing electrolysis.—*R. E. Thompson.*

The Determination of Iron and Manganese in Water. W. O. HEUBLEIN. Wasser, 16, 237–239 (1920). From Chem. Abst., **16:** 133, January 10, 1922. Iron is estimated by treating 100 cc. of the sample with 1 cc. of 3 per cent hydrogen peroxide, 5 cc. of hydrochloric acid, and 9 cc. of 20 per cent potassium thiocyanate, and comparing the color so obtained with known standards. The method is sensitive to 0.05 p.p.m. The amount of manganese (in p.p.m.) present in a water is equal to the number of cubic centimeters of phenolphthalein (5 mgm. per liter in 50 per cent alcohol) required to impart, to a solution of sodium hydroxide, a color of equal intensity to that obtained by adding to 10 cc. of the sample, in a test tube, 7 drops of sulphuric acid (1:3), a few crystals of potassium persulphate, and 7 drops of 5 per cent silver nitrate, and immersing in boiling water for 20 minutes. 0.3 p.p.m of manganese can be estimated by this method.—*R. E. Thompson.*

Manganese in Ground Water and its Removal. L. ZAMKOW. Z. Wasserversorgung Abwasserkunde, 7, 31–33 (1920). From Chem. Abst., **16:** 133, January 10, 1922. A filter is described by means of which as much as 1.1 p.p.m. of manganese can be removed from water. The taste of drinking water is not impaired by 5 p.p.m. of manganese, but such water cannot be used in certain industries, such as fermentation, laundry, and dye manufacturing.—*R. E. Thompson.*

Modern Water Purification. W. HEYM. Z. Wasserversorgung Abwasserkunde, 7, 70–72 (1920). From Chem. Abst., **16:** 133, January 10, 1922. Descriptions are given of the modern methods of purification, such as simple sand or alumina, ozone, ultra-violet radiation, calcium hypochlorite, aluminium sulphate, etc. No process can be considered as the ideal.—*R. E. Thompson.*

Grease in Boiler Feed Water. E. INGHAM. Colliery Guardian, 122, 447–448 (1921). From Chem. Abst., **16:** 134, January 10, 1922. Grease is considered to be the most objectionable ingredient in feed water. Many explosions have been caused by the presence of this substance, and the difference in temperature between the hot side and the water side of a boiler plate may be as much as 550°F. in the presence of grease, as compared with 68°F. under normal conditions. In water containing calcium or magnesium carbonates and grease, emulsions are formed through which the steam bubbles cannot pass, and the water is prevented from coming in contact with the boiler plate. At the present time chemical precipitation combined with filtration is the only means by which grease can be removed from water.—*R. E. Thompson.*

Hague Water Supply. A. H. PAREAU. Z. Wasserversorgung Abwasserkunde, 7, 43–45, 56–57 (1920). From Chem. Abst., **16:** 134, January 10, 1922.

A description of the Hague waterworks is given, dating from their inception in 1874. The latest type of filter consists of 75 cm. of beach sand, 15 cm. of river sand, 10 cm. of gravel, and four progressively coarser gravels 48 cm. thick.—*R. E. Thompson.*

Water Supplies of the Austrian Republic. A. SWETZ. Z. Wasserversorgung Abwasserkunde, 7, 59–61 (1920). From Chem. Abst., **16:** 134, January 10, 1922. A description of the water supply systems in Austria is given, the Vienna supply in particular being described in detail.—*R. E. Thompson.*

Denitrification as a Means of Sewage Purification. E. A. COOPER, Biochem. J., 15, 513–515 (1921). From Chem. Abst., **16:** 134, January 10, 1922. The incubation of sewage with nitrate solutions and filter effluents leads to the destruction of a considerable amount of oxidizable material, as is indicated by the fact that the oxygen absorption figures for mixtures of tank liquors and nitrate solutions or filters effluents are considerably lower than those for the corresponding mixtures of tank liquor and water only.—*R. E. Thompson.*

Taste of Chlorinated Water. F. W. SPERR, JR. Gas Age-Record, 48, 566–571 (1921). From Chem. Abst., **16:** 155, January 10, 1922. The objectionable taste imparted to chlorinated water by ammonia still waste can be avoided by mixing the waste with city sewage, the bacteria of which destroy the phenols. As much as 10 per cent of such waste can be mixed with the sewage.—*R. E. Thompson.*

Hydrogen ion Concentration and Color Removal. J. F. BREWSTER AND W. G. RAINES, JR. J. Ind. Eng. Chem. 13, 1043–1044 (1921). From Chem. Abst., **16:** 170, January 10, 1922. In experiments on the decolorization of cane juice with carbon it was found that the decolorization increases with an increase in H-ion concentration, within the range of pH 4 to 8.—*R. E. Thompson.*

Color and Hydrogen Ion Concentration. W. D. HELDERMAN AND V. KHAINOVSKY. Arch. Suikerind., 29, 1229–35 (1921). From Chem. Abst., **16:** 170, January 10, 1922. The color of tan liquors was found to change reversibly from light straw color at pH 3 to deep red at pH 12.—*R. E. Thompson.*

Canton Adopts Water Rate Zoning System. Editorial. Fire and Water Eng., 71: 2, 92, January 11, 1922. Canton, Ohio, divided into three zones, A, B and C. Zone payments are made four times a year, with no two zones paying during same month. Zone A payments January, April, July and October. Zone B payments February, May, August and November. Zone C payments March, June, September and December.—*A. W. Blohm.*

Removing Iron from Water Without Aeration. WALDO S. COULTER. Fire and Water Eng., 71: 4, 163, January 25, 1922. Special-closed system replaces aerator and rapid sand unit at Highstown, N. J. Water from 200-foot tube wells contains from 4 to 5 p.p.m. iron and 45 p.p.m. of carbon dioxide.

Closed system consists of withdrawal of water from wells and discharge through pressure filters, hydrated lime being applied by a dry feed machine, before filtration. Action of lime upon an iron-bearing water is found to be more rapid when operation is conducted under pressure. Where there is question of bacterial removal, this plant would hardly be applicable.—*A. W. Blohm.*

The City's Share of Water Expenses. Editorial. Fire and Water Eng., 71: 4, 174, January 25, 1922. Water Commissioners of Holyoke, Mass., call attention to fact that city should bear a part of the burden of the water expenses, especially in matter of fire protection and the rental of hydrants. This would eliminate dissatisfaction caused by the necessarily high water rents.—*A. W. Blohm.*

Zoning System in Water Works Billing. FRED. R. MORRIS. Fire and Water Eng., 71: 5, 207, February 1, 1922. City of Appleton, Wis., is divided into districts, with water bills for different districts due on different months, so that the collection of revenue is continuous throughout the year. Water bills of a different color are sent to the different districts. No increase in office force has been necessary, although the number of connections has been doubled.—*A. W. Blohm.*